10/1/02-3185

Engineering Evaluation/Cost Assessment

DNAPL Removal

Operable Unit 16 (Site 89)

Defense Re-Utilization and Marketing Office

at

Marine Corps Base

Camp Lejeune, North Carolina

Contract Task Order 181

October 2002

Prepared for

Department of the Navy

Atlantic Division

Naval Facilities Engineering Command

Under the

LANTDIV CLEAN II Program

Contract N62470-95-D-6007

Prepared by

CH2MHILL

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Executive Summary

Marine Corps Base (MCB) Camp Lejeune is a training base for the United States Marine Corps located in Onslow County, North Carolina. CH2M HILL and Baker Environmental were tasked by the Atlantic Division of the Naval Facilities Engineering Command (LANTDIV) to perform a Remedial Investigation/Feasibility Study (RI/FS) at Camp Lejeune Operable Unit No. 16, Site 89. Due to the discovery of dense non-aqueous phase liquids (DNAPLs), CH2M HILL and Baker Environmental are now tasked to perform an Engineering Evaluation/Cost Assessment (EE/CA) in accordance with *"Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA"*, (USEPA, August 1993) for Site 89.

Of the volatile organic compounds (VOCs) detected at Site 89, 1,1,2,2-perchloroethane (PCA) was the most prevalent and was found at the highest concentrations. Other solvents, such as trichloroethene (TCE) were detected, as were daughter products of PCA and TCE, such as 1,2-dichloroethene (1,2-DCE) and vinyl chloride. Analytical data from soil samples indicate the presence of two areas that are indicative of DNAPL. In the larger area, PCA concentrations range from 650 milligrams per kilogram (mg/kg) to 21,250 mg/kg. TCE was also detected at significant levels, ranging from 33 mg/kg to 11,100 mg/kg. In the smaller DNAPL area, the maximum concentration of PCA were 705 mg/kg and TCE were 1,230 mg/kg.

Four technologies were evaluated to remediate the DNAPL impacted areas. Table E-1 is the evaluation summary of the four technologies and table E-2 is a ranking of these technologies. Based on the effectiveness, implementability, and cost, Electrical Resistive Heating (ERH) is the recommended remedial technology for the Site 89 DNAPL.

TABLE E-1
Summary of Alternative Comparison

Evaluation Criteria	Alternative 1 Steam Injection/Stripping	Alternative 2 Electrical Resistive Heating	Alternative 3 Dynamic Underground Stripping	Alternative 4 VER, Pneumatic Fracturing, and In-Situ Oxidation
EFFECTIVENESS				
Overall Protection of Human Health and the Environment	Meets RAOs, however potential for downward contaminant migration and heterogeneous soil conditions make technology less effective.	Meets RAO through treatment.	Meets RAO through treatment	Meets RAOs, however potential for downward contaminant migration with fracturing and heterogeneous soil conditions make technology less effective.
Compliance with ARARs	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.
Long-term effectiveness and permanence	Risk reduction is provided through extraction.	Risk reduction is provided through extraction	Risk reduction is provided through extraction	Risk reduction is provided through treatment. Will take longer operational period.
Reduction of Toxicity, Mobility or Volume through Treatment	Reduces toxicity, mobility and volume of DNAPL through extraction.	Reduces toxicity, mobility and volume of DNAPL through extraction	Reduces toxicity, mobility and volume of DNAPL through extraction	Reduces toxicity, mobility and volume of DNAPL through treatment
Short-Term Effectiveness	Worker concerns are air emissions and working with steam. Air emission controls will be necessary.	Worker concerns are air emissions and working with electricity. Air emission controls will be necessary	Worker concerns are air emissions and working with steam and electricity. Air emission controls will be necessary	Worker concerns are air emissions and working with strong oxidants. Air emission controls will be necessary
IMPLEMENTABILITY				
Technical Feasibility	Technical restraints are primarily heterogeneous subsurface conditions that will limit subsurface steam flow.	No technical restraints.	Technical restraints are primarily heterogeneous subsurface conditions that will limit subsurface steam flow.	No technical restraints.
Administrative Feasibility	No administrative problems are expected.	No administrative problems are expected.	No administrative problems are expected.	No administrative problems are expected.
Availability of Services and Materials	Services and materials are available. Base steam line is near Site 89.	Services and materials are available. Power is available, but may have to be brought closer to site.	Services and materials are available. Base steam line is near Site 89. Power is available, but may have to be brought closer to site.	Services and materials are available.
State and Community Acceptance	This alternative is likely to be acceptable to the community.	This alternative is likely to be acceptable to the community.	This alternative is likely to be acceptable to the community.	This alternative is likely to be acceptable to the community.

TABLE E-1
Summary of Alternative Comparison

Evaluation Criteria	Alternative 1 Steam Injection/Stripping	Alternative 2 Electrical Resistive Heating	Alternative 3 Dynamic Underground Stripping	Alternative 4 VER, Pneumatic Fracturing, and In-Situ Oxidation
COST				
Capital Cost (Direct and Indirect)	$1,497,000 (expanded area) not cost effective for confirmed DNAPL area only	$1,313,000 (expanded area) $379,000 (confirmed DNAPL area only)	$1,666,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,329,000 (expanded area) $813,000 (confirmed DNAPL area only)
Total O&M Cost	$619,000 (expanded area) not cost effective for confirmed DNAPL area only	$1,447,000 (expanded area) $344,000 (confirmed DNAPL area only)	$1,523,000 (expanded area) not cost effective for confirmed DNAPL area only	$492,000 (expanded area) $406,000 (confirmed DNAPL area only)
Present Worth	$2,116,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,760,000 (expanded area) $723,000 (confirmed DNAPL area only)	$3,189,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,798,000 (expanded area) $1,200,000 (confirmed DNAPL area only)

TABLE E-2
Relative Ranking of Remedial Alternatives

Evaluation Criteria	Alternative 1 Steam Injection/Stripping	Alternative 2 Electrical Resistive Heating	Alternative 3 Dynamic Underground Stripping	Alternative 4 VER, Pneumatic Fracturing, and In-Situ Oxidation
Effectiveness	3	1	2	4
Implementability	2	1	3	4
Cost	1	2	4	3
Total	6	4	9	11

This table represents a comparison ranking of the technologies. The factors have equal weighting. The lowest score is the recommended technology.

1.0 Introduction

Marine Corps Base (MCB), Camp Lejeune was placed on the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) National Priorities List (NPL) effective November 4, 1989 (54 Federal Register 41015, October 4, 1989). Subsequent to this listing, the United States Environmental Protection Agency (USEPA), the United States Department of the Navy (DoN) and the Marine Corps entered into a Federal Facilities Agreement (FFA) for MCB, Camp Lejeune in 1991. The primary purpose of the FFA was to ensure that environmental impacts associated with past and present activities at the MCB are thoroughly investigated, and that appropriate CERCLA response and Resource Conservation and Recovery Act (RCRA) corrective action alternatives are developed and implemented as necessary to protect public health and welfare, and the environment.

Marine Corps Base (MCB) Camp Lejeune is a training base for the United States Marine Corps located in Onslow County, North Carolina. CH2M HILL and Baker Environmental were tasked by the Atlantic Division of the Naval Facilities Engineering Command (LANTDIV) to perform a Remedial Investigation/Feasibility Study (RI/FS) at Camp Lejeune Operable Unit No. 16, Site 89. Due to the discovery of dense non-aqueous phase liquids (DNAPLs), CH2M HILL is now tasked to perform an Engineering Evaluation/Cost Assessment (EE/CA) in accordance with "*Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA*", (USEPA, August 1993) for Site 89.

Site 89 is located near the intersection of "G" and Eighth Streets at MCB Camp Lejeune (Figure 1-1). Site 89 consists of the fenced portion of the Defense Re-utilization and Marketing Office (DRMO) area. The investigative area associated with Site 89 extends beyond the fence and includes wooded area to the east , south and west.

Site 89 was the location of the Base Motor Pool operations until 1988. From 1988 to June 2000, Site 89 was used primarily as a storage yard for the DRMO.

Site 89 contains several areas of contamination that have been investigated under the Installation Restoration (IR) Program since 1997. Originally, the focus of the investigations at the site was on a small area in the northern portion of the site that formerly contained a 550-

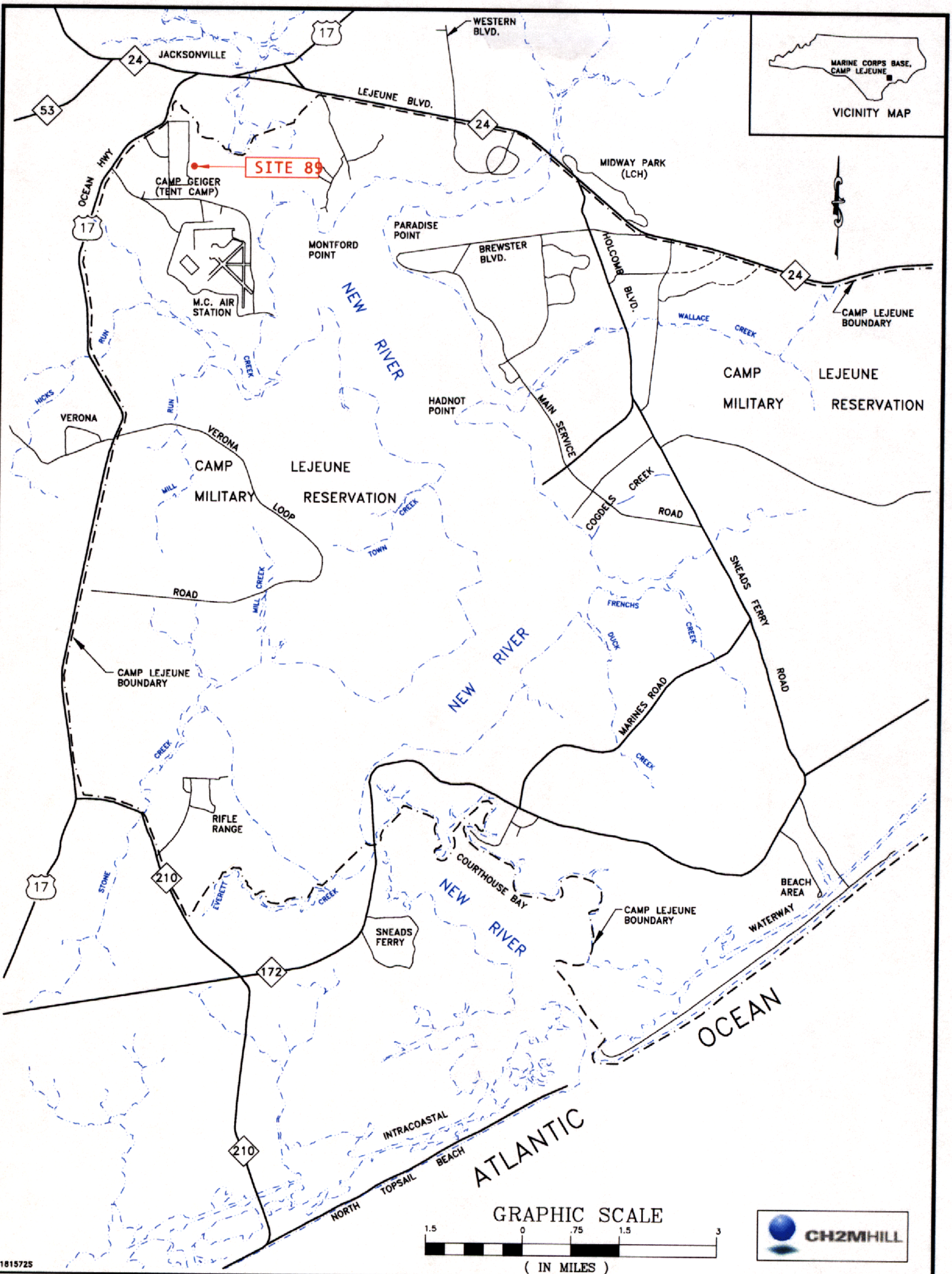


FIGURE 1-1
LOCATION MAP – SITE 89
ENGINEERING EVALUATION/COST ESTIMATE
SITE 89 – CTO 0181

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

gallon underground storage tank (UST) used to store waste oil. This UST was removed in 1993.

In April 1999, 1,1,2,2-tetrachloroethane (PCA) was detected in shallow groundwater monitoring well MW-02 located near the former UST. This discovery led to further investigations of the site in June/July 1999, October 1999, December 1999, March 2000, and April 2000. Investigations focused on the shallow vadose zone soils where data indicated the presence of dense non-aqueous phase liquid (DNAPL) below the water table.

The remedial alternatives presented and evaluated are designed to address DNAPL only. The actions are intended to remove as much DNAPL as technically feasible. However, DNAPL removal is complicated and current technologies are limited. Complete DNAPL removal is doubtful. Since this phase of work only addresses the DNAPL present at the site, dissolved contamination will remain. Additional treatment of the dissolved contamination will be required.

1.1 Purpose and Organization of the EE/CA

According to the United States Environmental Protection Agency (USEPA) *Guidance on Conducting Non-Time Critical Removal Actions Under CERCLA* (USEPA, 1993), "an EE/CA is a flexible document tailored to the scope, goals, and objectives of the non-time-critical removal action. It should contain only those data necessary to support the selection of a response alternative, and rely upon existing documentation whenever possible." The goals of an EE/CA are:

- "Satisfy environmental review requirements for removal actions,
- Satisfy administrative record requirements for improved documentation of removal action selection, and
- Provide a framework for evaluating and selecting alternative technologies."

The guidance further notes the following:

- a separate risk assessment is not necessary,
- data collection to characterize the nature and extent of contamination should be limited to those needed to support the specific objectives of the non-time-critical removal action, and

- only a few viable alternatives relevant to the EE/CA objectives should be identified and analyzed.

An EE/CA must be completed for all non-time critical removal actions under CERCLA, as required by section 300.415(b)(4)(i) of the NCP. The goals of the EE/CA are to identify the objectives of the remedial action and to analyze the effectiveness, implementability, and cost of various alternatives that may satisfy these objectives. Thus, an EE/CA serves an analogous function to, but is more streamlined than, the RI/FS conducted for remedial actions.

This EE/CA is organized as follows:

- Section 2 contains site characterization information, including site description and background, nature and extent of contamination, analytical data, and a streamlined risk evaluation.
- Section 3 contains an identification of Remedial Action Objectives (RAOs).
- Section 4 discusses remedial action alternatives.
- Section 5 details an analysis of remedial action alternatives based on effectiveness, implementability, and cost.
- Section 6 compares remedial action alternatives and presents a recommendation for the alternative that best satisfies the RAOs.
- Section 7 presents reference information.

2.0 Site Characterization

This section contains site characterization information including site description and background, nature and extent of contamination, and a streamlined risk evaluation.

2.1 Facility and Site Description

Background information for Site 89 is contained in the *Remedial Investigation of Operable Unit 16 (Sites 89 and 93)* (Baker Environmental, June 1998) and the *Supplemental Investigation Report* (Baker Environmental, August 2001). A detailed discussion of the Site background is contained in those reports.

2.1.1 Facility and Site Physical Setting

MCB Camp Lejeune is located in Onslow County, North Carolina and covers approximately 236 square miles and includes 14 miles of coastline. The Base is bounded to the southeast by the Atlantic Ocean and to the northeast by State Route 24. The town of Jacksonville, North Carolina is located north of the Base (Figure 1-1).

The generally flat topography of MCB, Camp Lejeune is typical of the seaward portions of the North Carolina coastal plain. Elevations at the Base vary from sea level to 72 feet above mean sea level (msl), although the elevation of the majority of the Base lies between 20 and 40 feet above msl.

The site area is relatively flat and covered by asphalt, gravel and grass. The eastern portion of the site is wooded and slopes gently toward Edwards Creek. Ground surface elevations are approximately 5 to 20 feet above msl in the vicinity of the site.

2.1.2 Site History

Prior to 1988, the southern area of the DRMO was used as the Base Motor Pool. Base personnel reported heavy use of solvents during that time. The DRMO operated at this location from 1990 to 2000.

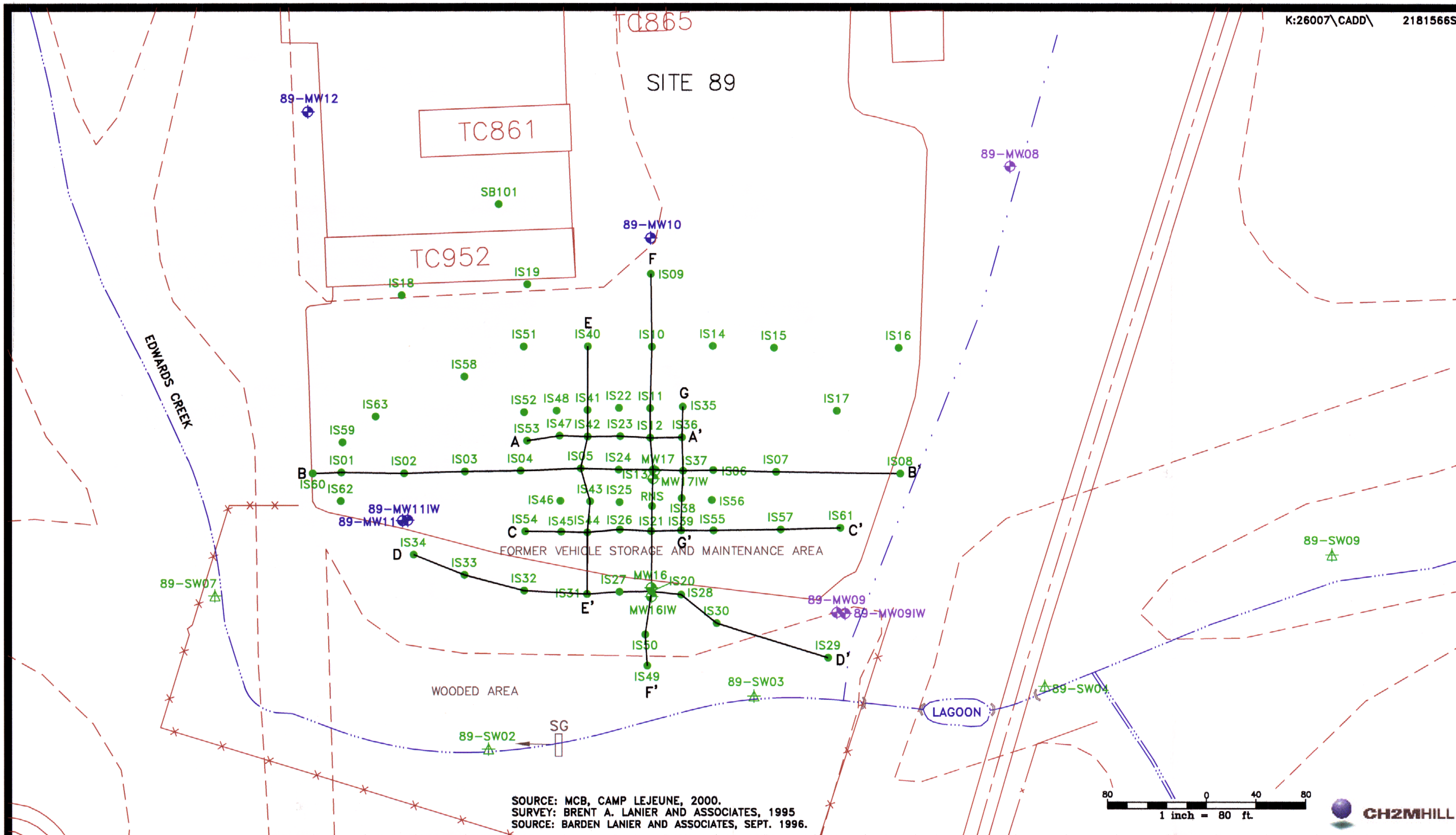
2.1.3 Soil and Lithologic Information

A detailed discussion of the soil and lithologies at Site 89 is presented in the RI Report (Baker, 1998). Information pertinent to Site 89 is summarized herein.

Site 89 is located in the Atlantic Coastal Plain physiographic province of North Carolina. The sediments of the Atlantic Coastal Plain consist of interbedded sands, clays, calcareous clays, shell beds, sandstone, and limestone. The Base is underlain by seven sand and limestone units separated by units which are comprised primarily of silt and clay. These include the surficial, Castle Hayne, Beaufort, Peedee, Black Creek, and the upper and lower Cape Fear lithologic units. The combined thickness of these units is approximately 1,500 feet.

For the Site 89 Supplemental Investigation (Baker, August 2001), Baker utilized a Membrane Interface Probe (MIP)/electrical conductivity probe to conduct site-specific stratigraphy characterization. Figure 2-1 shows cross-section locations from the MIP sampling. Figure 2-2 is the East to West Site Stratigraphy and Figure 2-3 is the North to South Stratigraphy. For further subsurface information, refer to the Site 89 Supplemental Investigation which contains soil boring logs for the site. Baker has identified three hydro-stratigraphic units at Site 89, which are the Undifferentiated Formation (surficial aquifer), the Belgrade formation (the Castle Hayne confining unit), and the River Bend Formation (Castle Hayne aquifer). It should be noted that the upper five feet of soils at the site are fill material from the previous removal action. On the figures, the blue line represents the top of the Belgrade formation. The green line represents the top of the River Bend formation. These contacts were determined from visual lithology characterization supported by the electrical conductivity probe.

The undifferentiated formation occurs at a depth of approximately 5 feet below ground surface (bgs). The undifferentiated formation tends to be sandy on the western and northern side of the site. Soil boring logs from the western area (IS01, IS03, and IS34) shows mainly fine sand and fine to medium sand layers interbedded with silt and clay layers. Cross sections show a large sandy lens wedged between finer grained sediments on the eastern side of the site. This wedge appears to thin toward the south. According to the boring logs from IS08 and IS30, the wedge is comprised mainly of fine to medium sand. The



LEGEND

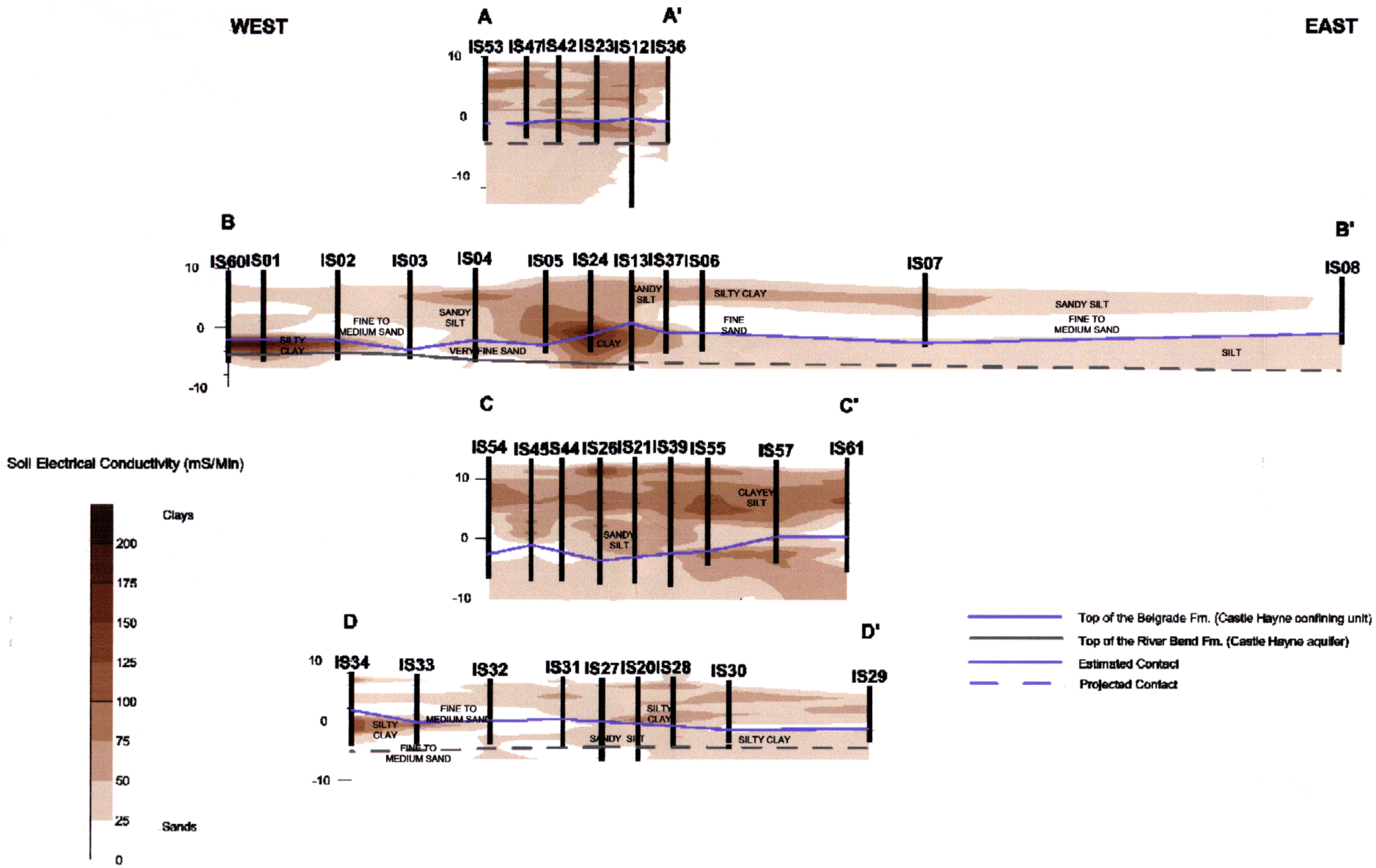
- SUPPLEMENTAL INVESTIGATION MONITORING WELL LOCATION
- SUPPLEMENTAL INVESTIGATION BORING LOCATION
- SURFACE WATER/SEDIMENT SAMPLE LOCATION
- GROUNDWATER MONITORING WELL (JUNE/JULY 1999)
- GROUNDWATER MONITORING WELL (OCT. 1999)
- FENCE LINE

A — A' - CROSS SECTION LINE

FROM BAKER SUPPLEMENTAL INVESTIGATION (AUGUST 2001)

FIGURE 2-1
CROSS SECTION LOCATION MAP
ENGINEERING EVALUATION/COST ESTIMATE
SITE 89 - CTO 0181
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

2181551S



CH2MHILL

60 0 30 60 120

Horizontal Scale: 1 inch = 60 ft.

20 0 10 20 40

Vertical Scale: 1 inch = 20 ft.

FIGURE 2-2
SITE STRATIGRAPHY
EAST TO WEST CROSS SECTIONS
ENGINEERING EVALUATION/COST ESTIMATE
SITE 89 – CTO 0181

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

FROM BAKER SUPPLEMENTAL INVESTIGATION (AUGUST 2001)

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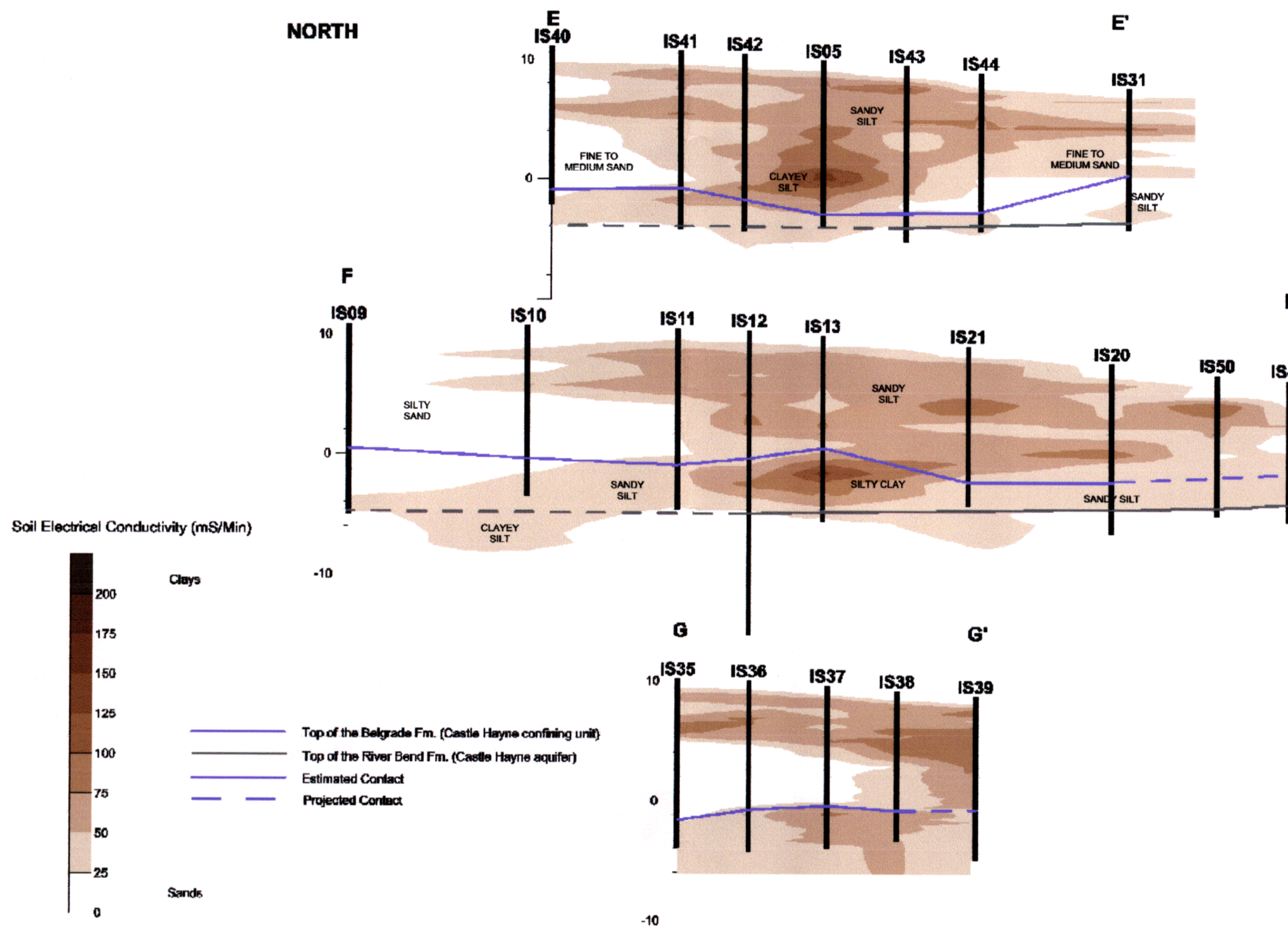

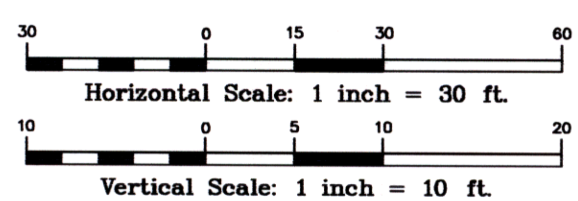

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FROM BAKER SUPPLEMENTAL INVESTIGATION (AUGUST 2001)

FIGURE 2-3
SITE STRATIGRAPHY
NORTH TO SOUTH CROSS SECTIONS
ENGINEERING EVALUATION/COST ESTIMATE
SITE 89 – CTO 0181

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

finer grained sediments are mainly silts and clays. An examination of the center of cross sections, indicate that the undifferentiated formation in the source area tends to be mainly finer grained sediments. Boring logs (IS11, IS13, and IS20) show interbedded silt and clay layers, fine and medium sand layers, and sandy silt layers. The overall appearance of these cross-sections illustrates the heterogeneous layering present in the undifferentiated formation.

The Belgrade formation (Castle Hayne confining unit) begins at a depth of approximately 8 to 15 feet bgs. This unit is distinguished by its olive green/gray color, presence of shell fragments, and a decrease in moisture content. As shown by the cross sections and supported by boring logs, the composition of this unit varies. Cross sections illustrate that the Castle Hayne confining unit is predominately a clay in the western and central portions of the site (e.g., IS01 and IS24), and is a fine silty sand or silt elsewhere (e.g., IS04 and IS08). The thickness of this unit varies from 2 feet to 6 feet and tends to be thickest in the central portion of the site.

The River Bend formation (the upper portion of the Castle Hayne aquifer) begins at a depth of approximately 14 to 20 feet bgs. This unit is distinguished by the presence of calcareous sands, shell fragments, and fossil fragments. Due to the dense nature of these sediments, the MIP was generally not able to penetrate very far into this unit. Boring logs from wells 89-MS16IW and 89-MW17IW indicate that the upper portion of the Castle Hayne aquifer is comprised of interbedded fine to medium sand, shell and fossil fragment layers and calcareous silt and clay layers. Another confining layer within the Castle Hayne aquifer is present beginning at a depth of about 38 feet bgs.

The geologic information indicates a definite hydraulic connection between the surficial aquifer and the underlying Castle Hayne aquifer. This connection is likely attributable to the discontinuous nature of the Castle Hayne confining unit rather than hydraulic conductivity through the unit. Hydrogeologic information from the RI report for this site as well as other nearby sites at Camp Geiger indicate that the Castle Hayne confining unit is non-existent or limited in lateral extent. Also, vertical hydraulic conductivity measurements indicate that the Castle Hayne confining unit exhibits a low hydraulic conductivity.

2.1.4 Hydrologic and Hydrogeologic Information

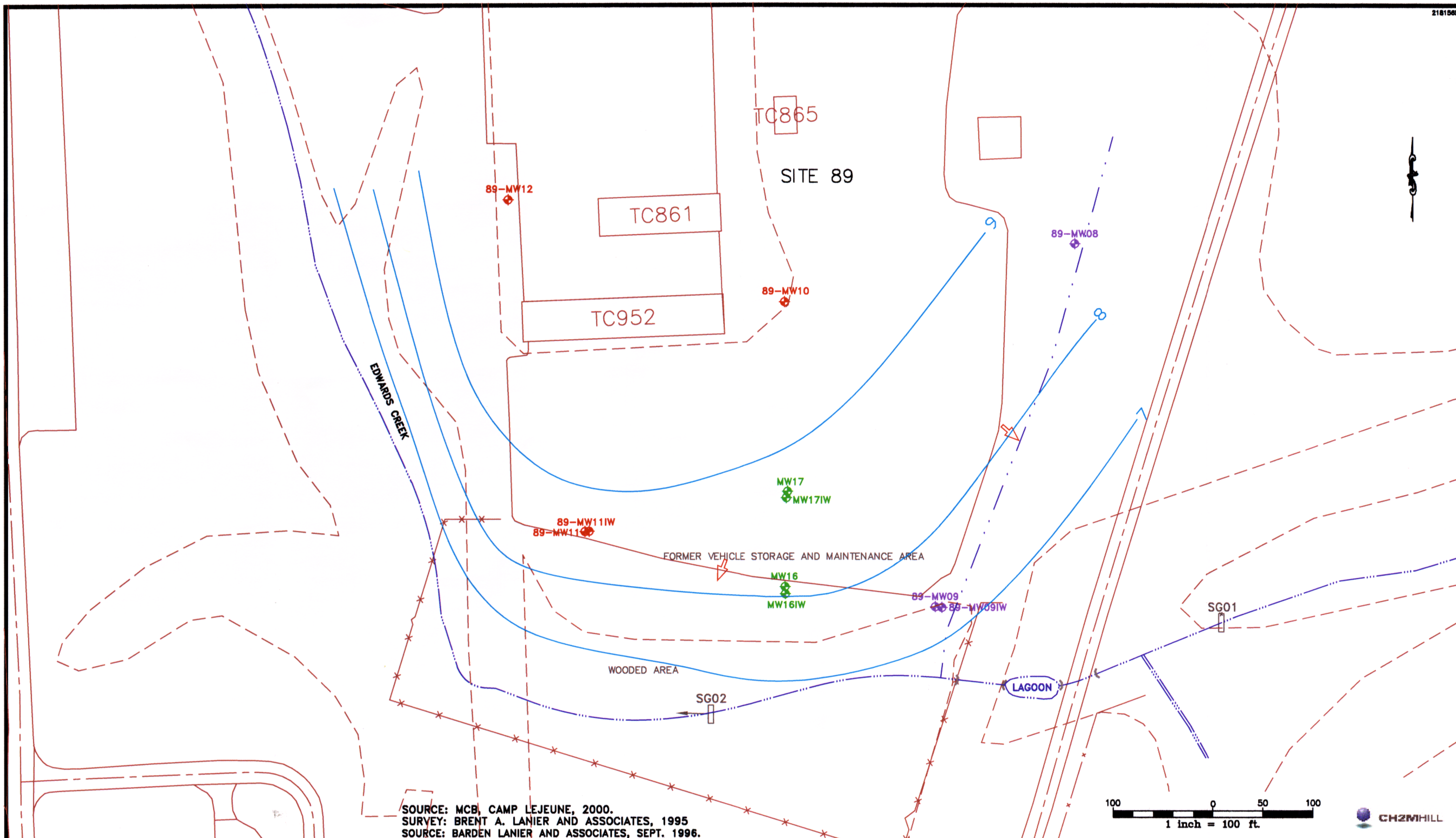
A detailed discussion of the hydrologic and hydrogeologic characteristics at Site 89 is presented in the RI Report (Baker, June 1998). Information pertinent to Site 89 is summarized herein.

The surficial aquifer consists of a series of sediments, primarily sand and clay, which commonly extends to maximum depths of 75 feet bgs. This unit is not used as a water supply on the Base.

The principal water supply for the Base is found in the series of sand and limestone beds that occur between 50 and 300 feet bgs. This series of sediments is generally known as the Castle Hayne Formation, associated with the Castle Hayne Aquifer. This aquifer is approximately 150 to 450 feet thick in the vicinity of the Base and is the most productive aquifer in North Carolina.

Clay layers occur in both of the aquifers. However, the layers are thin and discontinuous in most of the area, and no continuous clay layer separates the surficial aquifer from the Castle Hayne Aquifer. The clay layers range from 10 to 15 feet thick and comprise between 15 and 24 percent of the combined thickness of the two aquifers (Baker, 1998).

Groundwater elevations measured within site monitoring wells ranged from 2.15 feet below msl to 13.52 feet above msl (approximately eight to ten feet below ground surface). The groundwater elevation data suggest that the flow patterns observed for the surficial and upper portions of the Castle Hayne aquifers display similar trends. Overall, elevations are higher in the northern portion of the site, with decreasing elevations in the direction of Edwards Creek and in the wooded areas to the east. Groundwater flow in the surficial aquifer shows a pronounced localized flow toward Edwards Creek as it serves as a groundwater discharge boundary (Figure 2-4). Edwards Creek effects flow within the surficial aquifer and upper portions of the Castle Hayne aquifer more than in the deeper portion of the aquifer. Groundwater flow in the upper portions of the Castle Hayne aquifer (Figure 2-5) is affected somewhat by the local discharge area of Edwards Creek, but there is also a trend eastward demonstrating the effects of the surface water bodies associated with the New River. The New River, located east of the site, apparently influences the

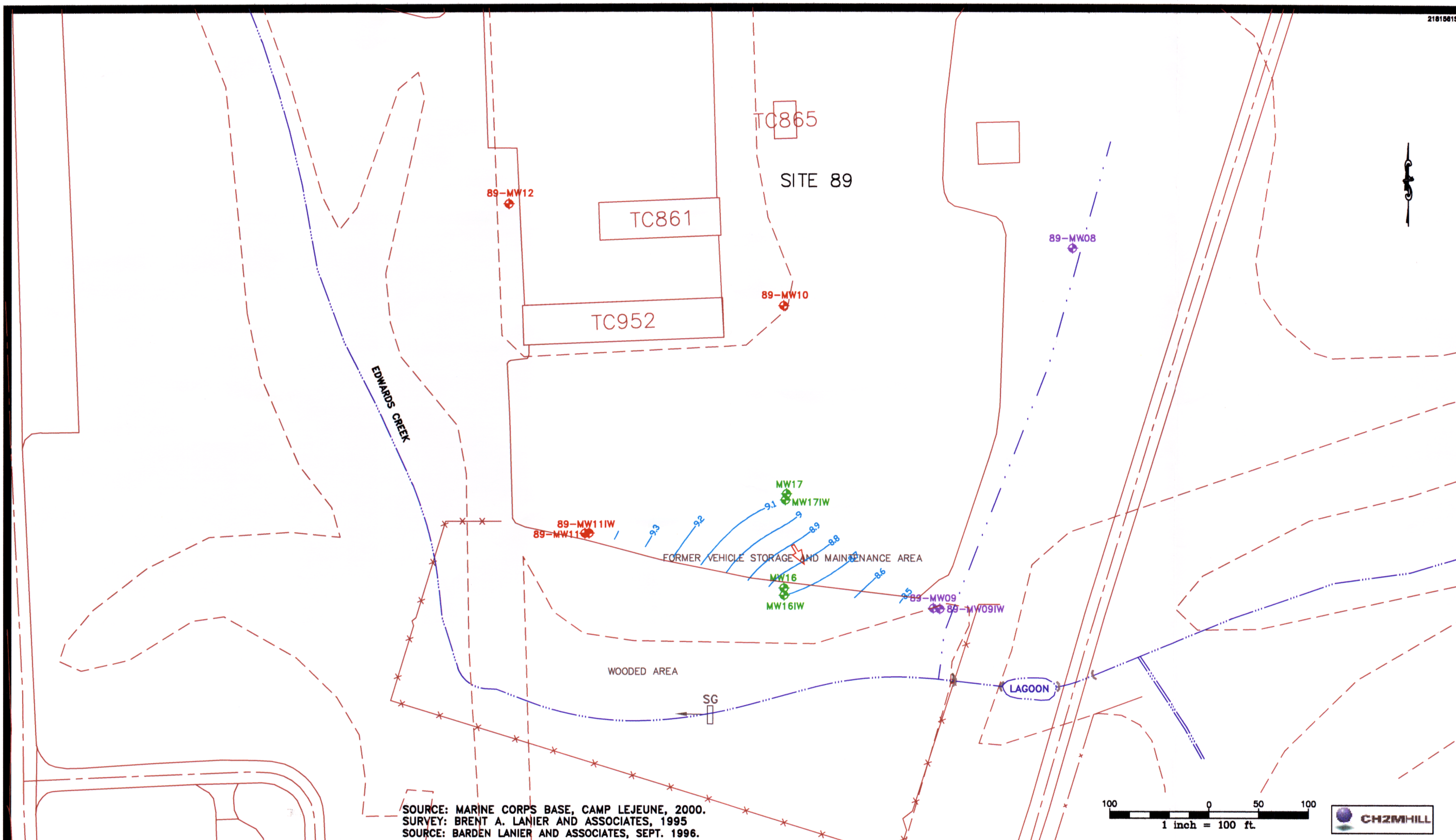


LEGEND

- – SUPPLEMENTAL INVESTIGATION MONITORING WELL LOCATION
- – GROUNDWATER CONTOUR LINE (FEET, MSL)
- – GROUNDWATER FLOW DIRECTION
- – GROUNDWATER MONITORING WELL (JUNE/JULY 1999)
- – GROUNDWATER MONITORING WELL (OCTOBER 1999)
- –X–X– FENCE LINE

NOTE: – WATER ELEVATIONS FROM APRIL 2001

FIGURE 2-4
SHALLOW GROUNDWATER
POTENTIOMETRIC SURFACE MAP
SUPPLEMENTAL INVESTIGATION
SITE 89 – CTO 0181
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



LEGEND

- SUPPLEMENTAL INVESTIGATION MONITORING WELL LOCATION
- GROUNDWATER CONTOUR LINE (FEET, MSL)
- GROUNDWATER FLOW DIRECTION
- GROUNDWATER MONITORING WELL (JUNE/JULY 1999)
- GROUNDWATER MONITORING WELL (OCTOBER 1999)
- FENCE LINE

FIGURE 2-5
INTERMEDIATE GROUNDWATER POTENTIOMETRIC SURFACE MAP
SUPPLEMENTAL INVESTIGATION
SITE 89 - CTO 0181
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

groundwater flow of the deeper portions of the Castle Hayne aquifer, causing groundwater at depth to move east, toward the river.

Groundwater head differentials between the shallow and intermediate wells have been evaluated to determine if a vertical component of flow underlies the site. In general, elevations in shallow temporary wells were greater than the associated elevation in the intermediate temporary wells in those well clusters located north of Edwards Creek. This data demonstrates a downward component of groundwater movement from the surficial aquifer to the Castle Hayne aquifer north of Edwards Creek. This information supports the assumption that confining conditions of the Castle Hayne aquifer in this area are not likely. The geologic and hydrogeologic information collected thus far further suggest that there is a definite, and in some places a significant, hydraulic connection between the surficial aquifer and the underlying Castle Hayne aquifer.

The surficial aquifer was characterized during the Supplemental Investigation (Baker, August 2001) by performing in-situ rising head slug tests in select shallow and intermediate monitoring wells. The geometric mean hydraulic conductivity (K_h) value as determined from five wells in the vicinity of the DNAPL release (89-MW9, 89-MW10, 89-MW11, 89-MW16, and 89-MW17) was estimated to be 0.311 ft/day (1.1×10^{-4} centimeters per second (cm/sec)) for the surficial aquifer, which is within the typical range for silty sands.

The horizontal hydraulic conductivity of the upper portion of the Castle Hayne aquifer is an order of magnitude greater than the surficial aquifer. Values range from 4.55 feet/day (1.61×10^{-3} cm/sec) at well MW17 to 10.88 feet/day (6.75×10^{-3} cm/sec) at well MW11. Sediments tend to be coarser and more transmissive in this unit, accounting for the higher conductivities.

The Castle Hayne confining unit has a laboratory-measured vertical hydraulic conductivity ranging from 2.0×10^{-5} cm/sec at boring IS06 to 8.3×10^{-6} cm/sec at well MW16IW. The confining unit is predominantly sand, with lesser amounts of silt and clay. Despite the low clay content, the hydraulic conductivity is low.

2.2 Previous Removal Actions

Elevated levels of chlorinated solvents were detected in the soil and groundwater at Site 89 during previous investigations. Contaminants detected at the site in exceedance of USEPA Region IX industrial soil preliminary remediation goals (PRGs) include PCA and vinyl chloride (VC). The contaminants that were present in the site soil were considered to be a potential source of groundwater contamination, which in turn may have contributed to surface water and sediment contamination in nearby Edwards Creek. In addition, concerns were also raised about worker exposure at the site.

The threat to industrial workers at the site was temporarily addressed by placing a high-density polyethylene (HDPE) tarp over the impacted, unpaved area in the southern portion of Site 89. Low temperature thermal desorption (LTTD) technology was selected to treat the impacted soils in an ex-situ setting, to reduce the potential threat of exposure.

OHM Remediation Services Corp. (OHM) [now IT Corporation] utilized LTTD technology to treat impacted soil excavated from Site 89 as a Time-Critical Removal Action (TCRA). PCA was selected as the remedial 'indicator' parameter and a value of 1 milligram per kilogram (mg/kg) was utilized as the treatment standard. The final volume of soil treated during the TCRA activities was approximately 23,788 cubic yards (35,682 tons).

The TCRA was conducted during the period from May 2000 to May 2001, and required extensive site preparation including construction of material and equipment storage areas, treatment areas, and use of an on-site analytical laboratory to provide real-time data.

2.3 Previous Investigations

The original investigation of Site 89 focused upon a small area within the DRMO which contained an UST identified as STC-868. The UST was a 550-gallon steel waste oil tank installed in 1983 located between Building STC-867 and an elevated wash rack. This UST was reported to be closed by removal in 1993.

The major finding of the initial UST closure investigation at Site 89 was the detection of chlorinated solvents in the groundwater. The presence of chlorinated compounds in groundwater is not generally associated with a petroleum UST site.

The discovery of chlorinated solvents led to the inclusion of Site 89 into MCB, Camp Lejeune's IR program. The current area of Site 89 has expanded to include more than the former UST area. Site 89 extends beyond the fence and includes wooded area to the east, south and west.

Investigations completed since the discovery of the chlorinated solvent release include:

- Remedial Investigation, Operable Unit 16, Sites 89 and 93, conducted during the summer of 1996 and the spring of 1997. (Baker, June 1998)
- Investigation of soil and groundwater, conducted during June and July 1999. (Baker, August 1999)

In addition, Site 89 has been included in the Base's long term monitoring (LTM) program since 1999. It was the detection of PCA during the LTM program that initiated the June/July 1999 investigation.

It was during the later phase of investigation that significant contamination was discovered in the southern portion of the site. Subsequent investigations of the southern portion of the site focused on the DNAPL and the shallow vadose zone soils. These investigations included:

- Investigation of soil, groundwater, surface water, and sediments, conducted during October and December 1999. (Baker, February 2000)
- Investigation of soil and groundwater, conducted during March 2000 and April 2000. (Baker, May 2000)
- Supplemental Investigation, Operable Unit 16, Site 89, conducted during June and July 2001. (Baker, August 2001)
- Additional sampling of soil and sediment along the north side of Edwards Creek in the Southwestern portion of Site 89. (conducted in September 2001, but no report at this time)
- An Addendum to the Supplemental Investigation, Operable Unit 16, Site 89, conducted in May 2002. (CH2M HILL, July 2002)

Each investigation is discussed in detail in its respective report. The following is a summary from each investigation.

The RI (Baker, June 1998) describes the detection of relatively low concentrations of VOCs in soil and groundwater in the southern portion of the site. It is noted that the majority of the maximum detections in soil occurred within samples collected from approximately 11 to 13 feet below ground surface (bgs).

The RI indicated that VOCs had migrated in groundwater to a depth of 40 to 50 feet bgs (the upper portions of the Castle Hayne aquifer), about 1,300 feet to the east of the former UST, and as far south as Edwards Creek. Site 89 is identified as the likely source area for both soil and groundwater contamination.

The February 2000 document prepared by Baker discussed the findings of site investigations at Site 89 during October and December 1999. This investigation concluded that the elevated concentrations of PCA in soil sample SB05-02 could indicate the presence of DNAPL.

In May 2000, Baker prepared a document summarizing the findings of site investigation activities conducted during March and April 2000. This work identified PCA and TCE in soil at Site 89 at concentrations indicating the possible presence of DNAPL. Baker also employed NAPLANAL (Mariner et. Al, 1997) to evaluate contaminant partitioning in the subsurface. NAPLANAL is a computer model that uses site-specific information (soil properties) and chemical properties to calculate partitioning results and provides an estimate of the percent of non-aqueous phase liquid.

The Supplemental Investigation identified two DNAPL zones below the water table in the southern portion of Site 89. Figure 2-6 shows the estimated horizontal extent of the DNAPL and extended source areas. PCA is the primary DNAPL in the larger of the two DNAPL zones (centered on boring IS13), and is estimated to have impacted approximately 2,000 cubic yards of soil. Trichloroethene (TCE) is the primary DNAPL in the smaller DNAPL zone (centered on boring IS01) and is estimated to have impacted approximately 50 cubic yards of soil. The extended source areas surrounding each DNAPL source zone are likely not completely delineated due to terrain-related access issues. The extended source areas were defined by reviewing groundwater concentrations available from the site. These areas represent groundwater concentrations greater than 10% of the solubility of TCE. This concentration is believed to be representative of a potential DNAPL source in the immediate vicinity of the data point. Due to the characteristics of DNAPL, it is probable that residual DNAPL is present within in this extended area.

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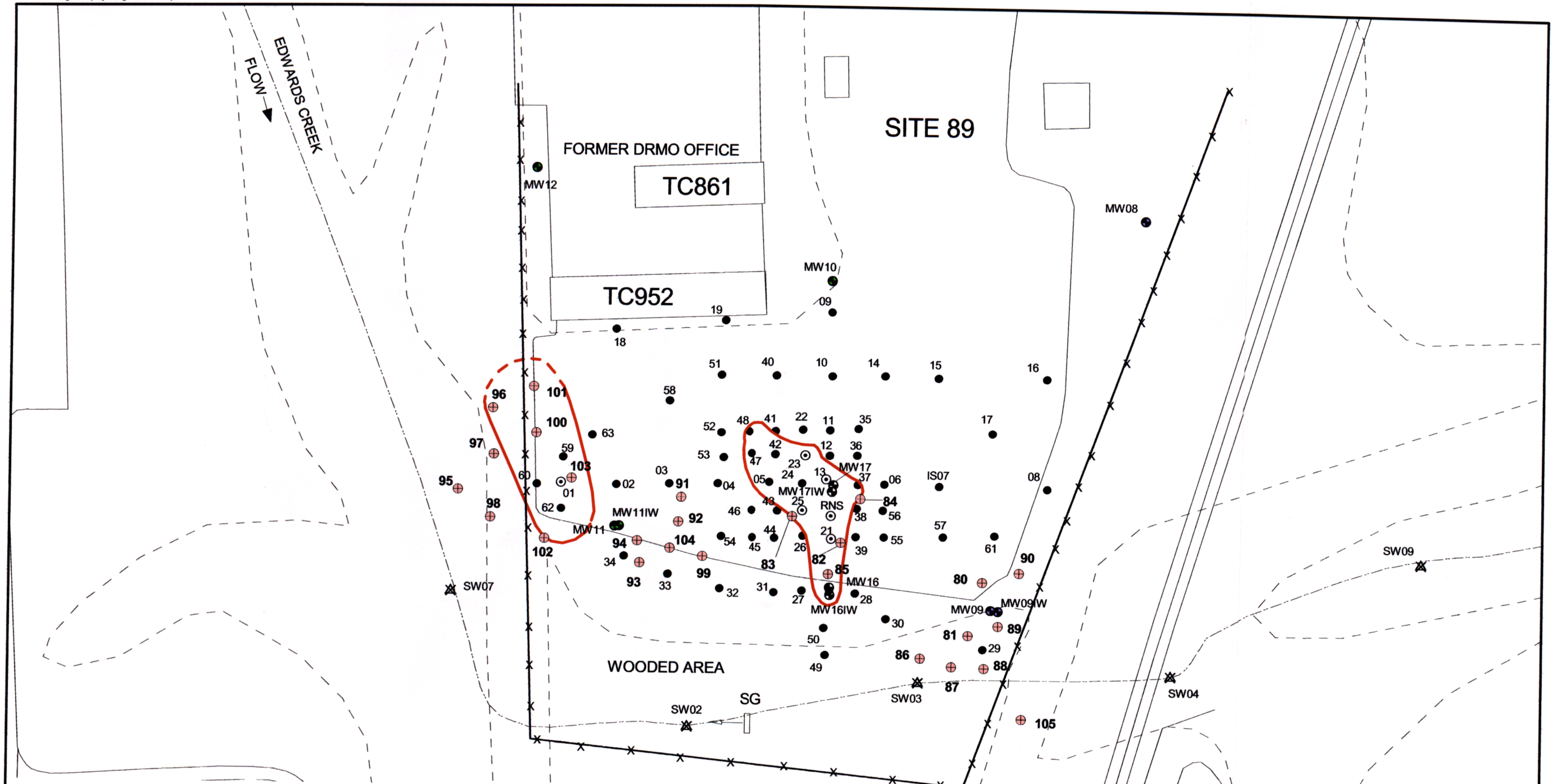

Source: LANTDIV, February 1992
Survey: Brent A. Lanier and Associates, 1995
Sorce: Barden Lanier and Associates, Sept. 1996, Oct. 1991

LEGEND

- Supplemental Investigation Monitoring Well Location
- Supplemental Investigation Boring Location
- Supplemental Investigation Surface Water / Sediment Sample Location
- Supplemental Investigation Boring With Ribbon NAPL Sampler
- SB80 New Supplemental Investigation Boring Location
- Groundwater Monitoring Well (June/July 1999)
- Groundwater Monitoring Well (October 1999)
- Fence Line
- Estimated Extent of DNAPL

From Baker Supplemental Investigation (August 2001)

N

0 50 100 Feet

Figure 2-6
Estimated Horizontal Extent of Source Areas
Site 89 - CTO 0181
Marine Corps Base, Camp Lejeune
North Carolina

CH2MHILL

The Supplemental Investigation also reported elevated concentrations of PCA and TCE in surface water and sediment samples collected from the floodplain of Edwards Creek, in the southwestern corner of the site. It was stated that these detections did not correlate with known site conditions, and therefore, maybe associated with another separate release.

The addendum to the Supplemental Investigation was to further delineate DNAPL plumes at the site. Soil samples, groundwater samples, head space analysis and dye shake tests were conducted as part of the investigation. The results indicated that Baker's extend eastern area probably did not contain DNAPL and the eastern DNAPL plume was as Baker indicated. However, the western DNAPL plume was found to be larger than Baker estimated, extending to the north and somewhat to the west. The depths of DNAPL were consistent with Baker's findings.

2.4 Nature and Extent of Contamination

A detailed discussion of the nature and extent of contamination is presented in the RI Report (Baker, June 1998) and Supplemental Investigation Report (Baker, August 2001).

Investigative activities conducted subsequent to the RI included the collection of soil and groundwater samples focusing on the southern portion of Site 89. More recently, additional phases of investigation have been conducted to better define the extent of DNAPL and dissolved-phase contamination; including membrane interface probe (MIP), ribbon NAPL samplers (RNSs), and real-time analyses using an on-site mobile laboratory.

2.4.1 VOCs

Of the VOCs detected at Site 89, PCA was the most prevalent and was found at the highest concentrations. Other solvents, such as TCE were detected, as were daughter products of PCA and TCE, such as 1,2-dichloroethene (1,2-DCE) and VC. However, PCA is a good indicator of the approximate extent of VOC contamination.

Figures 2-6 and 2-7 show the estimated horizontal and vertical extents of the DNAPL and extended source areas. There appear to be two separate DNAPL source zones, a larger, main DNAPL source zone in the central portion of the study area, and a smaller DNAPL source zone in the western portion of the study area.

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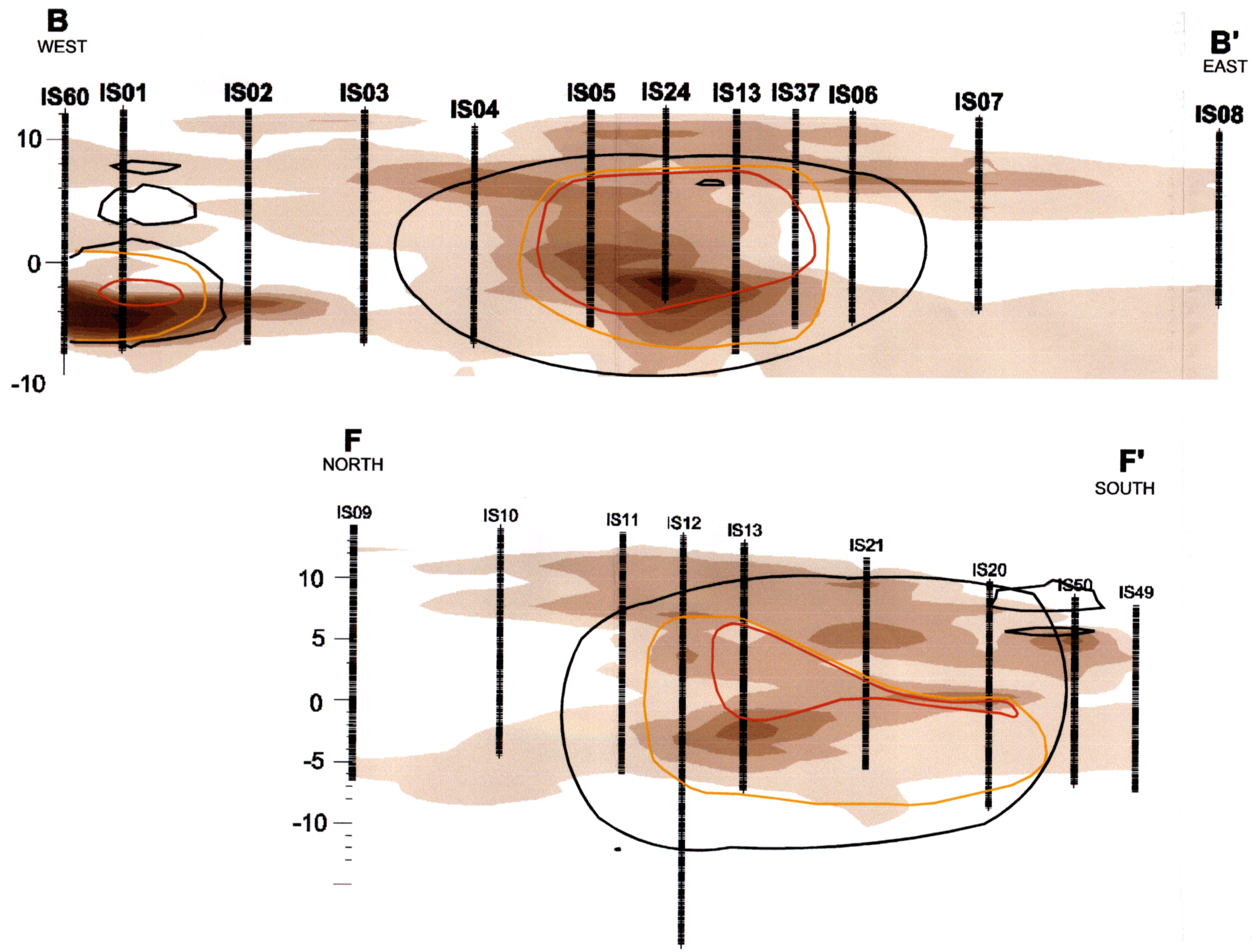


LEGEND

- ESTIMATED EXTENT OF DNAPL
- ESTIMATED EXTENT OF THE EXTENDED SOURCE AREA (110,000 ppb)
- ESTIMATED EXTENT OF THE EXTENDED SOURCE AREA (50,000 ppb)

FROM BAKER SUPPLEMENTAL INVESTIGATION (AUGUST 2001)

CH2MHILL

FIGURE 2-7
ESTIMATED VERTICAL EXTENT
OF SOURCE AREA
ENGINEERING EVALUATION/COST ESTIMATE
OPERABLE UNIT 16 (SITE 89) CTO – 0181

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

Analytical data from soil samples collected from the main DNAPL source zone indicate that PCA is the primary contaminant. Within the main DNAPL source zone, PCA concentrations range from 650 milligrams per kilogram (mg/kg) in IS25-04, to 21,250 mg/kg in IS13-05. TCE was also detected at significant levels in the main DNAPL source zone, ranging from 33 mg/kg in IS25-04 to 11,100 mg/kg in IS25-08. In the smaller DNAPL area, the maximum concentrations of PCA (705 mg/kg) and TCE (1,230 mg/kg) were both detected in IS01-07.

The estimated DNAPL source zones is based on soil samples containing concentrations exceeding 100 mg/kg. Only PCA and TCE were detected at or above these concentrations. During the field investigation, free-phase (mobile) DNAPL was observed in the main DNAPL source zone in three borings: IS13, IS21, and IS25. Borings IS24, IS37, and IS47 also were included in the main DNAPL source zone based upon MIP responses, and their location relative to visually confirmed DNAPL. In addition, further refinements of the DNAPL source zone estimations were conducted by partitioning analysis using NAPLANAL software.

The appearance of DNAPL in borings and wells and the high levels of soil concentrations tend to indicate the presence of DNAPL in both a mobile and residual form. The mobile DNAPL is present in the three borings: IS13, IS21, and IS25, whereas, the residual DNAPL accounts for the high soil concentrations.

2.5 Streamlined Risk Evaluation

According to USEPA *Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA*, (1993), "...[f]or the EE/CA, the streamlined risk evaluation should focus on the specific problem that the removal action is intended to address. If the action is intended to address a particular source of contamination, the risk evaluation should address the risks related only to that source of contamination." Since this EE/CA addresses only the removal of DNAPL as a source of further contamination in groundwater and surface water at the site, the risk evaluation is limited to DNAPL only.

The primary risk is the continuing source of contamination to groundwater and subsequently the creek from the DNAPL. By removing the DNAPL, the continuing contaminant source will be removed. Groundwater contamination will remain at the site and will be addressed separately by a final remedy.

3.0 Identification of Remedial Action Objectives

This section identifies the objectives of the non-time-critical removal action at Site 89. Based on information presented in Section 2.0, conditions at Site 89 warrant the evaluation of remedial action objectives (RAOs) for the protection of human health and the environment. The RAOs for the proposed interim corrective action are based upon the threat to groundwater and surface water posed by the presence of DNAPL in the surficial aquifer at Site 89.

The RAOs for Site 89 are:

- Reduce exposure and risk to human and ecological receptors.
- Prevent or minimize DNAPL migration to the Castle Hayne aquifer.
- Remove DNAPL accumulations to the extent practicable from the DNAPL and extended sources areas identified at Site 89.

3.1 Statutory Limits on Removal Actions

Non time-critical removal actions funded by EPA have a $2 million and a 12-month statutory limit pursuant to Section 104(c)(1) of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). Because removal actions at the MCB, Camp Lejeune are not being funded by EPA, these statutory limits do not apply. However, cost effectiveness is a recommended criterion for evaluation of the removal action alternatives.

3.2 Determination of Remedial Action Scope

The selected remedial action is intended to be an interim corrective action implemented at Site 89 to achieve the identified RAOs. The remedial action is intended to significantly reduce the amount of DNAPL present at the site to eliminate, to the extent possible, the ongoing source of groundwater and surface water contamination.

3.3 Determination of Remedial Action Schedule

Factors that may affect the remedial action schedule primarily relate to seasonal restrictions. For example, inclement weather (storms or hurricanes) can delay construction and operation of remedial systems.

Implementation of construction activities is anticipated to require 2 to 6 months based on the remedy selected. System operation may last for several years. The NCP requires a minimum public comment period of 30 days for this EE/CA.

4.0 Identification of Remedial Action Alternatives

General response actions that may be used to satisfy the RAOs include institutional controls, removal, containment, treatment, and disposal. In accordance with the EPA *Guidance On Conducting Non-Time-Critical Removal Actions Under CERCLA* (EPA, August, 1993), treatment technologies were selected in favor of capping or land disposal. Based on the removal action scope (Section 3.2), the objective of the interim remedy will be DNAPL mass removal or destruction in the saturated zone. The dissolved plume, and any residual source zone impacts, will be addressed by the final remedy for the site. In accordance with this objective, technologies selected for interim remedy evaluation must be capable of rapid extraction and/or destruction of DNAPL mass, in order to prevent delay of final remedy implementation and project closure. Technologies with demonstrated effectiveness in significantly reducing DNAPL mass are few, particularly at low permeability, heterogeneous sites such as Site 89. The following is a list of the technologies considered for further evaluation:

1. Excavation and On-Site Thermal Treatment
2. Steam Injection/Stripping
3. Electrical Resistance Heating (ERH)
4. Dynamic Underground Stripping (DUS)
5. Combined Vacuum Enhanced Recovery (VER), Pneumatic Fracturing, and In-Situ Chemical Oxidation/Reduction
6. Surfactant Enhanced Aquifer Remediation (SEAR)
7. Soil Mixing with Iron Addition

Three of these technologies, excavation, SEAR and soil mixing with iron addition, were eliminated from consideration, because of physical characteristics of the subsurface, logistical constraints, or technology uncertainties (lack of adequate development and testing).

Excavation and on-site thermal treatment was employed for the unsaturated zone during the time-critical removal action beginning July of 2000. At that time, excavation of the saturated zone was considered to be cost prohibitive because of the volume of impacted soil within the saturated zone, as well as anticipated expenditures associated with dewatering and slope stabilization.

SEAR is not applicable for low and moderate permeability, heterogeneous subsurface environments. At Site 89, injected surfactant solution would be expected to flow preferentially through higher permeability zones, leaving significant DNAPL mass adsorbed to silt and clay horizons. This assertion is substantiated by results of the SEAR demonstration for Site 88. The Site 88 demonstration, performed by Duke Engineering and Services, indicated that the technology was effective (i.e. > 92% removal efficiency) for shallow, higher permeability soil comprising the upper undifferentiated formation. However, the technology was not effective in terms of DNAPL mass removal from the lower permeability clay and silt near the interface of the Belgrade formation.

Soil mixing with iron addition uses large rotating auger blades (3 to 12 feet in diameter) to mix the soil and then a slurry of zero valent iron is added to oxidize the contaminants. Steam can also be injected during the soil mixing. The concept allows the augers to break up soil allowing the steam or oxidizing materials to provide better contact within the contaminated matrix. The increased contact maximizes the contaminant removal process. The major drawback is a high mobilization and capital cost. The system has been tested and demonstrated on several sites. Although initial testing appears to be successful, there is limited data for large-scale implementation and limited cost information. Cost estimates are not well quantified and the literature provides ranges of $100 to $200 per cubic yard. In comparison to other technologies evaluated in this document, soil mixing is not yet proven to be a cost effective treatment relative to the other technologies, therefore, this technology will not be evaluated further.

The streamlined list of technologies selected for feasibility review at Site 89 is therefore summarized as follows:

1. Steam Injection/Stripping
2. Electrical Resistive Heating

3. Dynamic Underground Stripping (DUS)
4. Combined VER, Pneumatic Fracturing, and In-Situ Chemical Oxidation/Reduction

It should be noted that the first three options are *extraction* technologies, which employ mass transfer from the liquid to the vapor phase as the primary vehicle for contaminant removal. As such, soil vapor extraction (SVE) plays an integral role in the successful implementation of each option. The last option includes a *destruction* technology, in-situ oxidation/reduction, which does not require SVE, vapor, or water (steam condensate) treatment.

Descriptions of each alternative are provided in this section. Section 5 contains the results of a detailed evaluation of the alternatives.

4.1 Option 1 – Steam Stripping/Injection

The process of heating the subsurface, by injecting steam, enhances SVE efficiency by increasing vapor pressure and volatilization rates of volatile and semi-volatile compounds. Reduction of viscosity and residual saturation of semi-volatile and nonvolatile compounds results from soil heating causing greater mobility and greater removal efficiency of mobile DNAPLs. Recovery of contaminants has been shown to consist of several component mechanisms: mobilization and recovery of separate-phase material, volatilization, enhanced aerobic and thermophyllic biodegradation, and in-situ hydrous pyrolysis oxidation (HPO) of dissolved phase contaminants.

HPO is a process that destroys DNAPLs and dissolved contaminants in place by hydrothermal oxidation. The technique involves injection of steam and oxygen (air) into the subsurface at elevated temperature (approximately 70°C or greater), creating a heated oxygenated zone that converts the contaminants to intermediate compounds and/or carbon dioxide and water.

Steam injection can be induced at the periphery, center or below the contaminated area to heat permeable and impermeable subsurface areas, vaporize volatile compounds and drive contamination to vacuum extraction wells. Steam will mobilize contaminants in permeable zones above and within an aquifer. The mobilized compounds are withdrawn from the geological formation by SVE. The minimum depth for the steam injection is typically 5 to 10 feet below the ground surface. At greater depths, the steam pressure can be increased, producing higher efficiencies and faster mass removal. Steam injection has been successfully applied to depths of 150 feet.

Advantages of Steam Stripping

- Steam injection is an aggressive contaminant extraction method, which can be used to remove DNAPL rapidly, often within several months.
- Steam injection enhances the volatility of contaminants, thus improving the efficiency of SVE.
- The HPO component of steam injection can be used in conjunction with subsequent enhanced bioremediation to degrade contaminants in-situ.
- Steam is generated at the Base and may be available for use at Site 89, reducing capital costs associated with construction of a temporary steam generation plant on-site. According to Mr. Tom Browley (General Foreman, Steam Generation), an abandoned steam conveyance line is located approximately 400 feet from the site, which could potentially be re-activated for service with limited capital expense. Mr. Browley indicated that up to 15,000 pounds per hour of steam could be made available.

Limits of Steam Stripping

- Steam injection requires installation of a relatively complex network of corrosion resistant (typically stainless steel) injection points, conveyance piping, valves, controls, and monitoring points. Capital costs are high.
- In cases where a sensitive receptor, such as a drinking water aquifer, occurs directly beneath the treatment zone, a portion of the receptor area can be heated to provide an extra measure of security. This technique is known as "hot floor" remediation. It is possible this technique could be used with steam, although steam injection in the Belgrade formation would be of questionable effectiveness, due to the low permeability of the formation.
- High injection pressures could result in vertical soil fracturing at shallow applications such as Site 89. Vertical soil fracturing may result in surface emission of fugitive steam and/or contaminated water (condensate), unless the area is contained with a cap (liner or paved). Low pressure, low flow steam injection is inefficient, and significantly extends project life.

- Steam stripping is best suited to high permeability, uniform soils. It may not be effective in low permeability zones without enhancement to improve secondary porosity and fluid transfer properties of the silt/clay.
- If not controlled, downward infiltration of steam condensate can impact underlying, uncontaminated zones.
- SVE vapor capture is required to prevent fugitive steam/vapor migration and possible recontamination of "clean" (previously remediated) vadose zone soil. Successful implementation of SVE may be challenging at Site 89, because of the moderate to low permeability of unsaturated zone. Since the site is unpaved, installation of a synthetic soil cover may also be necessary to prevent vertical air-flow "short-circuiting". SVE vapor treatment costs are expected to be relatively high. Air discharge permitting is required.

Implementation Concerns

1) *Potential for Air Emissions*

The potential release of air emissions to the atmosphere is greater at a site where thermal technologies are being used, because of the generation of contaminant-laden steam. Demonstration of steam capture by pilot testing and gas pressure monitoring will be necessary Site 89. The importance of vapor capture is further accentuated by the fact that the shallow unsaturated zone soil (previously treated during the time-critical removal action using on-site thermal desorption) is native material of relatively low permeability, making capture more difficult and vapor capture becomes a key control technology. In addition, the depth of soil cover (unsaturated zone) is shallow (approximately five feet). The shallow cover depth may increase the likelihood of vapor flow "short-circuiting" or fracturing during steam injection. More frequent and widespread air monitoring may be required, compared to high permeability sites with deep contamination. Air discharge permitting is required.

2) *Potential for Mobilization of DNAPLs Downward Into the Aquifer Due to Decreased Viscosity*

The potential for the mobilization of DNAPL downward into previously uncontaminated zones may be a concern. In addition to a demonstration of hydraulic capture, an investigation of the capacity of the Belgrade formation to retard downward migration of DNAPL and the ability to create a hot floor will be a requirement during pilot testing.

3) Physical Hazards Associated with High Pressure Steam

Physical safety will be a major concern. Hazards associated with handling and working with steam will require the use of barriers around the site and a proactive operation and maintenance program.

4.2 Option 2 – Electrical Resistive Heating

ERH is an in-situ thermal remediation technology developed at DOE's Pacific Northwest National Laboratory that uses electrical resistive heating, in conjunction with conventional SVE, to accomplish remedial objectives. For the purpose of the subject discussion, ERH is an all-inclusive term, which refers to both three-phase and six-phase heating technology.

Resistive heating occurs more rapidly in soils of high porosity and low permeability (silts/clays). As the soil is heated, vapor pressure and volatility of the mobile DNAPL is increased, while the viscosity of residual adsorbed DNAPL is decreased, improving mobility. Steam, laden with DNAPL vapor, is withdrawn by SVE and treated above ground. In-situ steam generation and subsequent dessication of the vadose zone may also improve permeability of clay-rich zones. Treatment times vary from several weeks to months, depending on site-specific conditions. ERH may also enhance biological activity in the soil column although any biological activity would not likely be a significant source of contaminant removal.

Advantages of ERH

- ERH offers the same advantages referenced in the previous section, with regard to steam injection.
- ERH is highly effective in low permeability soils, where heating actually occurs faster in clay rich soils than sandy material. ERH has a key advantage over conventional remedial methods such as air sparging or pump-and-treat, which are largely ineffective in low permeability media.
- Although steam condensate is generated during the process, the condensate is typically "clean" (i.e. less than discharge standards), since solvents and solvent mixtures have lower boiling temperatures than water. Most of the contaminants will have been vaporized and captured by the SVE system or broken down by the heating process.

- ERH is less prone to cause downward migration of contaminated steam condensate than steam injection, because the impacted saturated zone is boiled from underneath. In cases where a sensitive receptor, such as a drinking water aquifer, occurs directly beneath the treatment zone, a portion of the receptor area can be heated to provide an extra measure of security. This technique is known as "hot floor" remediation.

Limits of ERH

- Capital costs are high relative to other remedial technologies.
- SVE vapor capture is required to prevent fugitive steam/vapor migration and possible recontamination of the vadose zone. Successful implementation of SVE may be challenging at Site 89, because of the moderate to low permeability of unsaturated zone. Because the site is unpaved, installation of a synthetic cover may be necessary. SVE vapor treatment costs are expected to be relatively high. Air discharge permitting is required.

Implementation Concerns

1) *Potential for Air Emissions*

The potential release of air emissions to the atmosphere is greater at a site where thermal technologies are being used. The importance of vapor capture is further accentuated by the fact that the shallow unsaturated zone soil (previously treated during the time-critical removal action using on-site thermal desorption) is native material of relatively low permeability, making capture more difficult and vapor capture becomes a key control technology. In addition, the depth of soil cover (unsaturated zone) is shallow (roughly five feet). The shallow cover depth may increase the likelihood of vapor flow "short-circuiting" or fracturing during steam injection. More frequent and widespread air monitoring may be required, compared to high permeability sites with deep contamination. Air discharge permitting is required.

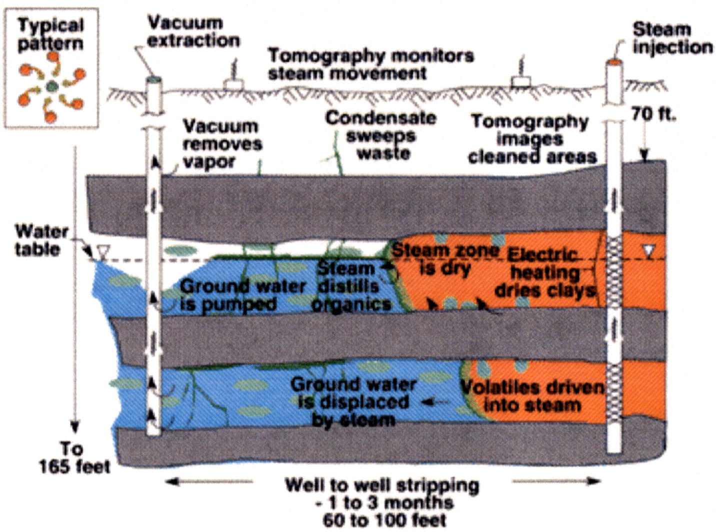
2) *Physical Hazards Associated with Electricity*

Physical safety will be a major concern. Hazards associated with working with electricity will require the use of barriers around the site and a proactive operation and maintenance program.

4.3 Option 3 – Dynamic Underground Stripping

Dynamic underground stripping (DUS) is a general term for steam stripping/HPO, which has been modified to include optional combined application of steam injection and ERH, simultaneously. In the context of this EE/CA, "DUS" refers exclusively to this combined approach. A conceptual schematic diagram of DUS is included below for reference. Under certain conditions, DUS can offer a particularly aggressive and effective method for rapid DNAPL removal. Such conditions are "layered" hydrostratigraphic or hydrogeologic units of dissimilar permeability/hydraulic conductivity. Localized, interbedded sand and clay/silt horizons within a single unit, such as the undifferentiated formation at Site 89, are also good candidates for DUS application.

In a layered formation (like Site 89) where permeability/hydraulic conductivity varies significantly with depth or spatial distribution, the distinct advantages of steam stripping and ERH can be used to complement one another. Therefore, DUS can expedite the rate of DNAPL mass removal, relative to steam injection or ERH alone.



Dynamic Underground Stripping Schematic Diagram

Advantages of DUS

- As previously described, DUS is particularly well suited to application in layered, heterogeneous soils or undifferentiated formations, where the distinct advantages of both steam injection and ERH can be exploited to maximum effect. Under such conditions, steam injection would be expected to rapidly heat and volatilize mobile DNAPL within relatively high permeability lenses. ERH would be used to simultaneously drive adsorbed DNAPL out of low permeability silt and clay zones and into the high permeability areas, to be purged by high flow steam. Therefore, improved mass transfer resulting from a combined steam stripping/ERH approach under such conditions would reduce project life.

Limits of DUS

- The disadvantages of DUS are essentially a combination of the disadvantages previously cited for steam injection and ERH. Another disadvantage is the high capital costs, since both steam injection piping and injection equipment, as well as ERH equipment, must be mobilized to the site, constructed, monitored, and disassembled at the conclusion of the project. Cost effective implementation of DUS under suitable conditions, relative to steam injection or ERH alone, is highly dependent on the ability of the design engineer(s) to use each technology to maximum advantage, in terms of DNAPL mass removal. Pilot testing of steam injection would likely be necessary prior to full-scale DUS design and implementation.

Implementation Concerns

1) *Potential for Air Emissions*

The potential release of air emissions to the atmosphere is greater at a site where thermal technologies are being used. The importance of vapor capture is further accentuated by the fact that the shallow unsaturated zone soil (previously treated during the time-critical removal action using on-site thermal desorption) is native material of relatively low permeability. In addition, the depth of soil cover (unsaturated zone) is shallow (approximately five feet). The shallow cover depth may increase the likelihood of vapor flow "short-circuiting" or fracturing during steam injection. More frequent and widespread air monitoring may be required, compared to high permeability sites with deep contamination. Air discharge permitting is required.

2) Physical Hazards Associated with Electricity and Steam

Physical safety will be a major concern. Hazards associated with working with electricity and steam will require the use of barriers around the site and a proactive operation and maintenance program.

4.4 Option 4 – Combined Vacuum Enhanced Recovery, Pneumatic Fracturing, and In-Situ Chemical Oxidation/Reduction

This option entails the combined use of three relatively common technologies. Two phases of work are expected with this scenario. The first phase would consist of operation of vacuum enhanced recovery (VER) until mass recovery drops off. At this point permeability enhancement using pneumatic fracturing would be conducted to increase recovery, and then followed with a polishing step injecting oxidation/reduction chemicals (phase two). The duration of phase one is expected to be two years, depending on the volume of DNAPL mass encountered, the heterogeneity of the subsurface, and prevalence of low permeability zones. After the bulk DNAPL mass has been recovered, in-situ chemical oxidation/reduction chemicals would be injected to "polish" the residual (phase two), thus achieving 95 to 99% removal.

Direct in-situ chemical oxidation/reduction of bulk DNAPL, in lieu of initial vacuum enhanced recovery, is not recommended. The subsurface conditions make this process unfeasible and there is little control over oxidant migration. Such reactions can be powerfully energetic, possibly even explosive, under certain conditions. Furthermore, in-situ chemical oxidation/reduction of bulk DNAPL would be cost-prohibitive, because of the sheer volume of oxidant required to destroy the bulk contaminant.

VACUUM ENHANCED RECOVERY

Vacuum enhanced recovery (VER) is a general term for vacuum assisted groundwater, NAPL and soil vapor recovery. Many subtle variations of VER exist, also known as "dual phase recovery", "multi phase extraction", "bioslurping", etc. However, the basic premise of this technology is the same: application of strong vacuum (10-25 inches mercury) to a sealed recovery well. Vacuum application increases yield and capture zone of the well, in terms of three-phase fluid recovery (groundwater, NAPL, and vapor). VER is effective in moderate permeability soil (in the range of 10^{-4} cm/s). However, the presence of low permeability (10^{-5} cm/s or less) silt/clay lenses, such as those present within the undifferentiated formation at Site 89, would be expected to retard the effectiveness of VER. "Rebound" or "tailing" effects would be expected, significantly extending the time required to achieve project goals and extract DNAPL mass.

PNEUMATIC FRACTURING

Pneumatic fracturing is a unique approach to enhance permeability and improve extraction of DNAPL from low permeability zones using VER. Pneumatic fracturing can be described as a process whereby a gas is injected into the subsurface at pressures sufficient to overcome the interstitial cohesive and capillary forces that bond (in the case of clay) the soil particles together. Flow volumes are also increased to a point exceeding the natural permeability to air-flow. The result of this action is the propagation of "fractures" outward from the injection point. Unconsolidated materials such as silts and clays typically exhibit fracture propagation distances of 20 - 40 feet. In most formations, the propagation is relatively uniform around the injection well.

Relatively low pressures (typically less than 100 psig) are required to initiate fractures (the "nucleation" pressure). Flow volume is critical to the process. Typical injection events require gas flow into the formation at rates as high as several thousand cubic feet per minute (cfm). The low pressure, high volume injection creates a dense fracture network emanating from each injection location. Hydraulic conductivity can be increased by an order of magnitude and permeability by several orders of magnitude using this technology. Once the clay/silt zones are fractured, DNAPL recovery from these zones becomes feasible and cost-effective.

CHEMICAL OXIDATION/REDUCTION

Chemical oxidation-reduction (redox) reactions are essentially an exchange of electrons between chemical species. This exchange of electrons affects the oxidation state (valence) of the species involved. As a result, carbon bonds are broken, and the organic compounds are either completely destroyed or converted to less complex and, relatively, less hazardous compounds. Recent advances in the development of this technology include systems that effectively deliver and distribute reagents into soil and ground water so that in-situ chemical reactions are possible. In-situ chemical oxidation/reduction can be nonselective with regard to target compounds and has been demonstrated to be effective on halogenated and non-halogenated volatile compounds, as well as semivolatiles and polychlorinated biphenyls (PCBs), pesticides, and cyanides.

Remediation success using redox reactions is highly dependent on the ability to deliver the oxidant to the contaminated area. As is the case with in-situ thermal and soil flushing technologies, low soil permeability and heterogeneity can be problematic for redox remediation. However, as in the case of vacuum enhanced recovery, pneumatic fracturing can be used to enhance the effective permeability of the subsurface, and significantly improve the efficiency of oxidizing/reducing agent delivery. Oxidizing agents proven to be effective in the field include sodium/potassium permanganate, hydrogen peroxide, Fenton's reagent, and ozone. These oxidizing agents may be injected in liquid slurry or gaseous form. The most common reducing agent currently in field use is "zero-valent" or elemental iron (Fe^0), which is injected in powdered, solid form. Some of these oxidizing agents have limitations. For example, Fenton's reagent requires a low pH and site conditions may prevent this. Permanganate is not as effective on chemicals with single bonds, such as PCA. If this alternative is pursued further, the appropriate oxidizing agent will have to be carefully identified and tested.

Advantages of Combined VER, Pneumatic Fracturing, and Redox

- Equipment associated with VER is relatively inexpensive to install, operate, and maintain. In-situ redox does not require the installation of any equipment. VER is a proven technology, with a large number of successful case histories.
- There is no risk of downward plume migration with either VER or in-situ redox, however pneumatic fracturing could create vertical fractures, but this is a low probability.
- Pneumatic fracturing can be economically applied to the vadose zone, in conjunction with saturated zone fracturing, to improve SVE vapor capture. SVE vapor capture is a key component of the remedial process at Site 89, and improvements in vadose zone permeability to air-flow resulting from pneumatic fracturing can be several orders of magnitude.

Limits of Combined VER, Pneumatic Fracturing, and Redox

- The time frame required to achieve the project objective (DNAPL mass extraction) is subject to a greater degree of uncertainty than that associated with thermal remediation options previously discussed. The project life associated with this option is expected to be two to three years, at minimum, including redox "polishing". Accordingly, costs associated with this approach are also subject to a greater degree of uncertainty.
- Although the hydraulic conductivity of the undifferentiated formation is moderate to low, the volume of groundwater recovered by the VER process may be significant (pilot testing would be required to verify this assertion). Recovered groundwater would need to be treated above ground (air stripping, carbon adsorption, etc) and discharged to the wastewater treatment plant via the sanitary sewer, or to surface water via the storm sewer. A permit(s) would need to be obtained for this discharge (as well as air discharge permitting). Vapor and purged groundwater treatment equipment would need to be operated and maintained for the duration of the VER portion of the project.
- Additional pneumatic fracturing (thus increased costs) may be required in certain areas to "re-dilate" the existing fractures at the time of redox injection. In this manner, the volume of redox fluid injected is maximized.
- Undesirable intermediate compounds may be formed by in-situ redox, although such compounds are typically short-lived in the environment. Possible causes of intermediate product formation include: 1) incomplete oxidation (caused by insufficient quantity of either oxidant or catalyst), 2) presence of interfering compounds (electron exchange "sinks", such as naturally organic-rich media, as well as inorganic compounds such iron and manganese, etc.), which consume reagents, and 3) inadequate mixing or contact time between contaminant and oxidizing agent.

Implementation Concerns

1) *Potential for Air Emissions*

Since VER will be used, there is a potential release of air emissions to the atmosphere. Air discharge permitting is required.

2) *Fate of Injected Chemicals*

The primary concerns for in-situ redox are typically associated with fate of the redox chemicals once they are injected, particularly if an underlying aquifer (such as the Castle Hayne) may be threatened by such injection activity. Other regulatory concerns may include monitoring of treatment performance, because of the difficulty of locating and sampling DNAPL source areas, and possible formation of intermediate products. Of course, potentially dangerous (highly energetic) subsurface chemical reactions with DNAPL are also a concern.

3) Working with Strong Oxidants

Once again, worker safety will be a primary concern. There are issues concerning handling and injecting strong oxidants.

5.0 Detailed Analysis of Remedial Action Alternatives

The alternatives analysis uses the three main evaluation criteria of effectiveness, implementability, and cost, in accordance with the *U.S. EPA's Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA* (USEPA, 1993). Each evaluation criterion is described in Table 5-1. Appendix A provides reference information used to develop the cost estimates for the four alternatives.

TABLE 5-1
Evaluation Criteria

Effectiveness	
Protection of human health and the environment	The assessment describes how the action achieves and maintains protection of human health and the environment and achieves site-specific objectives both during and after implementation.
Compliance with ARARs	An alternative is assessed in terms of its compliance with ARARs, or if a waiver is required, how it is justified.
Short-term effectiveness	An action is assessed in terms of its effectiveness in protecting human health and the environment during the construction and implementation of a remedy before response action objectives have been met. The duration of time until the response objectives are met is also factored into this criterion.
Long-term effectiveness and permanence	An action is assessed in terms of its long-term effectiveness in maintaining protection of human health and the environment after response action objectives have been met. The magnitude of residual risk and adequacy and reliability of post-removal site controls are taken into consideration.
Reduction of toxicity, mobility or volume through treatment	An action is assessed in terms of anticipated performance of the specific treatment technologies it employs. Factors such as volume of materials destroyed or treated, the degree of expected reductions, the degree to which treatment is irreversible, and the type and quantity of remaining residuals are taken into consideration.
Implementability	
Technical feasibility	The ability of the technology to implement the remedy is evaluated.
Administrative feasibility	The administrative feasibility factor evaluates requirements for permits, zoning variances, impacts on adjoining property, and the ability to impose institutional controls.
Availability of services and materials	The availability of offsite treatment, storage, and disposal capacity, personnel, services and materials, and other resources necessary to implement the alternative will be evaluated.
State and community acceptance	The acceptability of an alternative to the state agency and the community is evaluated.
Cost	
Direct and indirect capital costs	Includes costs for construction, equipment and materials, analytical services, engineering and design, and permit/licenses.
Operation and maintenance costs	Includes ongoing monitoring and maintenance for a specific period.

5.1 Effectiveness

As explained in Section 3, the RAOs for Site 89 are:

- Remove DNAPL accumulations from the DNAPL and extended source areas identified at Site 89.
- Prevent or minimize DNAPL migration to the Castle Hayne aquifer.
- Reduce risk to human and ecological receptors.

5.1.1 Protection of Human Health and the Environment

The four options presented all meet RAOs for the site. Each is suitable for bulk DNAPL removal from the subsurface and reduction of risk to ecological receptors. Options one through three meet RAOs by mass transfer to the vapor phase (heating/boiling) and SVE vapor capture or cause *in situ* hydrolysis to breakdown the contaminants (both DNAPL and dissolved phase). Option four meets RAOs by physical extraction (VER) and in-situ destruction (chemical oxidation/reduction).

In order to improve vapor capture and mitigate the possible risk of fugitive vapor migration, it may be necessary to install a temporary cover, such as a geo-synthetic liner at the site. Permeability enhancement in the vadose zone may also be required to meet RAOs. SVE pilot testing would be necessary to verify the possible need for a cover and/or permeability enhancement.

A possible risk associated with the thermal technology options (1-3), particularly steam injection (option 1), is the chance of forcing contamination deeper into the formation, even the upper Castle Hayne aquifer. In order to mitigate this risk, preventative measures, such as the "hot floor" method (refer to section 4.1) would be implemented. Pilot scale testing may also be performed to evaluate potential risk to the saturated soils underlying the Belgrade formation.

5.1.2 Compliance with ARARs and Other Criteria, Advisories, and Guidance

The following list of applicable or relevant or appropriate requirements (ARARs) was developed based on the scope of work expected for potential DNAPL removal actions being evaluated in this EE/CA.

- Applicable state and federal guidelines for air, surface water, and/or sewer discharge associated with the collection and treatment of soil vapor and impacted groundwater will be complied with, in accordance with NCDENR requirements.
- Materials found to be characterized as a hazardous waste, if any, will be properly managed, stored, manifested, and shipped offsite in accordance with 40 CFR 261 - 268.
- Applicable Occupational Safety and Health Administration (OSHA) health and safety regulations will be followed wherever removal actions are deemed to be necessary. Workers performing the removal actions will be properly trained and under appropriate medical supervision. Appropriate personal protective equipment (PPE) will be used and appropriate safe work practices will be followed.
- The objective of interim source removal actions will be abatement of DNAPL to the maximum extent possible. The dissolved phased contamination will be addressed later. Accordingly, preliminary remediation goals (PRGs) for groundwater, such as NCDENR 2L standards, are not applicable.

5.1.3 Long-Term Effectiveness and Permanence

All four options consist of source removal technologies, which are expected to be permanent DNAPL treatment remedies at Site 89. These technologies are designed to remove a majority of DNAPL, but cannot achieve total DNAPL removal. Remaining soil contaminant concentrations may be one to ten percent of initial concentrations. In addition, since the contaminated zone is heterogeneous, concentrations after treatment are expected to also be variable. For example, there may be areas where the concentration is 0.5 mg/kg or 50 mg/kg and other areas where it is 500 mg/kg. At the conclusion of the interim action, it may be possible for impacted groundwater in the immediate vicinity of the treated area to cause low level recontamination of groundwater where DNAPL was previously present. Because the source zone is located upgradient of the dissolved plume, this effect would be expected to be limited to diffusion, resulting from concentration gradients. In any case, the dissolved groundwater plume will be addressed by the final remedy for Site 89. Therefore, such effects are not expected to have a detrimental impact on long-term effectiveness or permanence of the interim source abatement remedy.

5.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion relates to the preference in the CERCLA program for alternatives that include treatment. All four options presented are treatment options designed to reduce the toxicity, mobility, and volume of DNAPL at the site through extraction, mass transfer, and above ground vapor treatment and/or in-situ destruction. Contaminant removal is anticipated to be 90 to 99 percent.

5.1.5 Short-Term Effectiveness

Thermal treatment options 1 through 3 are all rapid source removal technologies, capable of achieving 80% to 99% removal from target areas in less than one year. Option 4, combined VER, pneumatic fracturing, and in-situ reduction and oxidation, is also an accelerated extraction/destruction approach designed to achieve 80% to 99% removal within two to three years. A pilot test may present an opportunity to measure actual contaminant removal or destruction under site conditions. There is some worker risk with working with steam or electricity and some oxidants. Care will have to be taken during remedial design, construction, implementation, and operation.

5.2 Implementability

Implementability consists of technical feasibility, administrative feasibility, availability of services and materials, and state and community acceptance.

5.2.1 Technical Feasibility

From the standpoint of technical feasibility, the primary concern associated with all four options presented is SVE vapor capture. An SVE pilot test is recommended to evaluate the feasibility of SVE, estimate the "zone of influence" for vacuum distribution and subsurface air flow, determine the possible need for surface soil cover to prevent air flow "short-circuiting", and estimate contaminant concentrations in the extracted soil gas. If possible, SVE testing should be conducted in conjunction with steam stripping testing to obtain a more accurate indication of VOC collection.

The primary concern associated with Option 1, steam injection, is the shallow depth of injection. Steam injection would occur along the depth of contamination. Five to ten feet of cover soil is generally considered "borderline" criteria for this technology, and shallow depth of injection will significantly reduce steam flow and pressure, which will in turn extend the life of the project. If steam injection is selected for additional evaluation, pilot testing is recommended to assess the potential for soil fracturing above the steam injection point, the distribution of steam in the subsurface, and the potential for forcing DNAPL into a lower formation.

A technical concern associated with ERH (Option 2) is possible downward DNAPL migration, which can likely be addressed by so-called "hot floor" treatment.

Technical concerns associated with DUS (Option 3) are the same as that for steam injection and ERH.

Technical concerns for VER/pneumatic fracturing/in-situ redox (Option 4) include extracted groundwater treatment, control of pneumatic fracturing, and formation of intermediate redox products. If selected for further evaluation, pilot testing for VER is recommended to verify the groundwater and vapor extraction capture zone, estimate rates of groundwater and vapor extraction, determine optimum design vacuums/flow rates, and favored method of application (dual phase recovery, bioslurping, etc). Intermediate products of PCA and TCE oxidation/reduction are not expected to be persistent in the environment. However, bench scale testing could be performed with native saturated soil to determine the potential for epoxide formation.

5.2.2 Administrative Feasibility

Although the thermal technologies presented are relatively new, there is sufficient case history information available in the literature to substantiate their effectiveness and safety. The issue of possible downward DNAPL migration would need to be addressed in the corrective action plan, using pilot test data and/or field data from sites similar to Site 89. Similarly, the issue of SVE vapor capture will need to be addressed via pilot testing and presentation of field data. The results of in-situ redox bench scale testing may also be required, if this option is selected for implementation.

5.2.3 Availability of Services and Materials

With regard to options 1 and 3, steam is generated at the Base and may be available for use at Site 89. According to Mr. Tom Browley (General Foreman, Steam Generation), an abandoned steam conveyance line is located approximately 400 feet from the site, which could potentially be re-activated for service, with limited capital expense. If steam heating is selected for further evaluation, the location of this steam line, it's overall condition, and available service pressure/flow would need to be verified in the field. The total steam demand for remediation activity at Site 89 is conservatively estimated to be 8,000 pounds per hour. Mr. Browley estimates that 10,000 to 15,000 pounds per hour could be delivered to the site, assuming conveyance piping is available and in good condition.

ERH uses a step-down transformer to convert 12.4 to 13.8 kV power, carried by most overhead power lines. Site 89 does have power running to it and the power lines may have to be extended approximately 100 feet to the ERH power supply unit. It may be necessary to install additional power poles, if the existing poles and available power are a significant distance from the site.

5.2.4 State and Community Acceptance

State and community acceptance will be evaluated continually and the assessment revised accordingly as members and representatives of the State and community provide comments on the remedial action process. These comments will be taken into account in the selection of the remedial action to be implemented.

5.3 Cost

Table 5-2 summarizes the direct and indirect capital costs, as well as long-term operation and maintenance costs (as applicable) for the four alternatives. As discussed previously in Section 2, there are two separate areas of impact within Site 89. Volumes and areas are based on calculations performed by Baker Environmental, and documented in the *Technology Evaluation Report* (included in the August 2001 *Supplemental Investigation Report*). As shown in Figure 2-6, known DNAPL areas are indicated in red, while suspected DNAPL areas are indicated in yellow.

TABLE 5-2

Preliminary Budget Level Cost Estimates for Technology Options

Scenario 1 – Address all suspected DNAPL Areas (Red and Yellow Zone)

Option	Capital Costs	Total Operational Costs	Total Cost	Cost/Cubic Yard*	Project Life	Present Worth
Option 1 – Steam Injection	$1,497,000	$619,000	$2,116,000	$92	< 1 year	$2,116,000
Option 2 – ERH	$1,313,000	$1,447,000	$2,760,000	$120	< 1 year	$2,760,000
Option 3 – DUS	$1,666,000	$1,523,000	$3,189,000	$138	< 1 year	$3,189,000
Option 4 – VER/Frac/Redox	$2,329,000	$492,000 (2 years)	$2,821,000	$122	2 years	$2,798,000

Scenario 2 – Address confirmed DNAPL Areas (Red Zone only)

Option	Capital Costs	Total Operational Costs	Total Cost	Cost/Cubic Yard*	Project Life	Present Worth
Option 2 – ERH	$379,000	$344,000	$723,000	$353	< 1 year	$723,000
Option 4 – VER/Frac/Redox	$813,000	$406,000 (2 years)	$1,219,000	$595	2 years	$1,200,000

Notes:
* Cost per cubic yard is based on the Total Cost divided by the amount of soil treated.
Present Worth for options 1-3 is a direct summation of costs, since the project life for these options is less than one year. Present worth for option 4 is based on a 3.2% discount rate.
During the course of the cost analysis, it was determined that the small volume/area associated with Scenario 2 was not cost effective for steam injection or DUS; therefore, Scenario 2 was eliminated for options 1 and 3.
For option 4, it was assumed that VER would be used to extract all DNAPL and 80% of groundwater contamination, prior to implementation of in-situ redox. Three potential redox amendments were evaluated: potassium permanganate, Fenton's reagent, and zero valent iron. Potassium permanganate was determined to be the most cost-effective reagent; therefore, the cost for application of potassium permanganate alone was assumed for this summary.

For the purpose of the cost analysis, two source removal "scenarios" were developed.

Scenario 1 - An aggressive approach designed to address all suspected DNAPL areas.

- Source removal for both the DNAPL and extended source area (yellow and red zones). The extended DNAPL source area is characterized by total VOC concentrations in excess of 100 mg/kg, based upon calculations conducted by Baker, included in the *Technology Evaluation Report*.
- This area consists of 23,000 cubic yards of impacted saturated soil, over an area of 56,500 square feet.
- The remedial goal for this scenario is significant removal of DNAPL and a 99% reduction of total VOC concentration in groundwater.

Scenario 2 - A focused, lower cost approach designed to address only those areas **known** (through visual confirmation) to contain DNAPL (i.e., the red zone).

- Source removal for the DNAPL area ("red zone"), for both Zone A and B. The known DNAPL area is characterized by total VOC concentrations in excess of 1,000 mg/kg, as calculated by Baker.
- The known DNAPL area consists of 2,055 cubic yards of impacted saturated soil, over an area of 8,750 square feet.
- The remedial goal for this scenario is removal of significant DNAPL and 95% reduction of total VOC concentrations in groundwater.

Direct capital costs pertain to construction, equipment, materials, and subcontractor labor (including overhead and profit). Direct capital costs were estimated based on quotations provided by the vendor and/or estimates by CH2M Hill staff experienced with the technology of concern. Indirect capital costs pertain to design, legal fees and permits, and include contingency/royalty fees, as applicable. Operational costs include professional services, consumables, laboratory fees, etc. These costs are generally used to calculate the "present worth" of the entire project, assuming a discount factor.

For Options 1 through 3, the life of the project is expected to be less than one year, therefore, the present worth is simply a summation of direct capital, indirect capital, and operational costs. For Option 4, the present worth was calculated assuming a two-year project life, with a 3.2% discount rate. Follow-on remedial actions, including long-term monitoring, to address dissolved phase contamination are not included.

All costs presented herein are preliminary estimates, intended for comparison purposes only. Appendix A contains additional information used to develop these costs.

During the course of the cost analysis, it was determined that the small volume/area associated with Scenario 2 was not cost effective for steam injection or DUS; therefore, Scenario 2 was eliminated for options 1 and 3.

For option 4, it was assumed that VER would be used to extract all DNAPL and 80% of groundwater contamination, prior to implementation of in-situ redox. Three potential redox amendments were evaluated: potassium permanganate, Fenton's reagent, and zero valent iron. Potassium permanganate was determined to be the most cost-effective reagent; therefore, the cost for application of potassium permanganate alone was assumed for this summary

5.4 Summary of Evaluation

Table 5-3 summarizes the evaluation for each technology.

TABLE 5-3
Summary of Alternative Comparison

Evaluation Criteria	Alternative 1 Steam Injection/Stripping	Alternative 2 Electrical Resistive Heating	Alternative 3 Dynamic Underground Stripping	Alternative 4 VER, Pneumatic Fracturing, and In-Situ Oxidation
EFFECTIVENESS				
Overall Protection of Human Health and the Environment	Meets RAOs, however potential for downward contaminant migration and heterogeneous soil conditions make technology less effective.	Meets RAO through treatment.	Meets RAO through treatment	Meets RAOs, however potential for downward contaminant migration with fracturing and heterogeneous soil conditions make technology less effective.
Compliance with ARARs	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.	Complies with ARARs. Will require air permit.
Long-term effectiveness and permanence	Risk reduction is provided through extraction.	Risk reduction is provided through extraction	Risk reduction is provided through extraction	Risk reduction is provided through treatment. Will take longer operational period.
Reduction of Toxicity, Mobility or Volume through Treatment	Reduces toxicity, mobility and volume of DNAPL through extraction.	Reduces toxicity, mobility and volume of DNAPL through extraction	Reduces toxicity, mobility and volume of DNAPL through extraction	Reduces toxicity, mobility and volume of DNAPL through treatment
Short-Term Effectiveness	Worker concerns are air emissions and working with steam. Air emission controls will be necessary.	Worker concerns are air emissions and working with electricity. Air emission controls will be necessary	Worker concerns are air emissions and working with steam and electricity. Air emission controls will be necessary	Worker concerns are air emissions and working with strong oxidants. Air emission controls will be necessary
IMPLEMENTABILITY				
Technical Feasibility	Technical restraints are primarily heterogeneous subsurface conditions that will limit subsurface steam flow.	No technical restraints. ERH is much less restricted by heterogeneous subsurface conditions.	Technical restraints are primarily heterogeneous subsurface conditions that will limit subsurface steam flow.	No technical restraints. Fracturing will compensate for heterogeneous and low permeability subsurface conditions.
Administrative Feasibility	No administrative problems are expected.	No administrative problems are expected.	No administrative problems are expected.	No administrative problems are expected.
Availability of Services and Materials	Services and materials are available. Base steam line is near Site 89.	Services and materials are available. Power is available, but may have to be brought closer to site.	Services and materials are available. Base steam line is near Site 89. Power is available, but may have to be brought closer to site.	Services and materials are available.
State and Community Acceptance	This alternative is likely to be *acceptable to the community.*	This alternative is likely to be *acceptable to the community.*	This alternative is likely to be *acceptable to the community.*	This alternative is likely to be *acceptable to the community.*
COST				
Capital Cost (Direct and Indirect)	$1,497,000 (expanded area) not cost effective for confirmed DNAPL area only	$1,313,000 (expanded area) $379,000 (confirmed DNAPL area only)	$1,666,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,329,000 (expanded area) $813,000 (confirmed DNAPL area only)
Total O&M Cost	$619,000 (expanded area) not cost effective for confirmed DNAPL area only	$1,447,000 (expanded area) $344,000 (confirmed DNAPL area only)	$1,523,000 (expanded area) not cost effective for confirmed DNAPL area only	$492,000 (expanded area) $406,000 (confirmed DNAPL area only)
Present Worth	$2,116,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,760,000 (expanded area) $723,000 (confirmed DNAPL area only)	$3,189,000 (expanded area) not cost effective for confirmed DNAPL area only	$2,798,000 (expanded area) $1,200,000 (confirmed DNAPL area only)

6.0 Comparative Analysis of Remedial Action Alternatives

The relative effectiveness of each of the four options was compared using the three criteria summarized in Section 5: effectiveness, implementability, and cost.

6.1 Effectiveness of Alternatives

Based on field case histories, all of the options reviewed have been proven effective in a variety of subsurface environments. However, some are more effective than others in challenging conditions, such as the heterogeneous, low permeability soils characterizing the undifferentiated formation at Site 89.

The technology with the best overall "track record" under such challenging conditions is ERH. Because ERH does not rely upon physical fluid transfer properties of the soil matrix to achieve performance, heterogeneous, low permeability soils do not present a barrier to rapid, efficient remediation. All of the other technologies are limited, to one extent or another, by the fluid transfer properties of the soil.

In the case of Site 89, assuming continuous, low permeability "layers" are present (as indicated in the drilling logs), other thermal remediation methods may prove effective. These low permeability lenses, which tend to retain DNAPL by adsorption, can be heated indirectly by thermal conduction from adjacent high permeability zones. This is the goal of steam heating/DUS, to rapidly strip contaminants out of high permeability zones, and use heat conduction and diffusion processes to volatilize DNAPL and VOCs out of interbedded low permeability layers. Therefore, steam injection and DUS are limited by the continuity (or lack thereof) of the "high permeability" layers.

VER is similarly limited by low permeability zones, which can result in "rebound" or "tailing" effects. Pneumatic fracturing was presented as a possible approach to "break apart" clay-rich zones, increasing advective fluid flow and expediting DNAPL and impacted groundwater recovery rates. Residual DNAPL not readily drained by gravity (with the assistance of vacuum application) or volatilized are destroyed in place using in-situ oxidation/reduction, after formation fracturing and VER is completed.

To summarize, in terms of the predictability and assurance of effectiveness, ERH is considered to be the first choice, followed closely by DUS, then steam injection and VER/fracturing/in-situ redox, with the latter two being essentially equal.

6.2 Implementability of Alternatives

The four options presented are aggressive, state-of-the-art approaches to DNAPL recovery, destruction, and site remediation. As such, they require the use of specialized equipment and materials, which may be proprietary and/or involve high mobilization, set-up, decontamination, and demobilization costs. All four require vapor capture using soil vapor extraction, which may be difficult at Site 89, considering the thickness and permeability of the vadose zone (refer to the "limits" section of each technology description in section 4.0 for additional information).

Because the site is a low traffic area, site disturbance with any of these options is expected to be limited. Of greater concern to implementability are subsurface conditions, as they relate to technology application and the possible need for additional temporary or semi-permanent soil cover to control vapor migration. Such concerns are best evaluated in the field during a pilot test. Field evaluation is recommended for all options, however pilot testing for ERH can be relatively expensive as ERH does not lend itself well to small-scale pilot testing. VER, in particular, is a common technology, which can be readily tested at low cost. Costs associated with steam pilot testing will be significantly greater, depending on the availability of steam service to the site, because of increased set-up and monitoring expenditures associated with the technology.

6.3 Cost of Alternatives

Note from review of Table 5-2 that the cost per cubic yard of soil treated for "Scenario 2" (which entails a focused, localized approach to source removal only in areas where DNAPL has been visually confirmed to be present, "red zone") is disproportionate to "Scenario 1" unit costs. These disproportionate costs are associated with an economy of scale - relative cost effectiveness of treating larger areas of the site at one time, primarily because of the fact that equipment mobilization, set-up, monitoring, decontamination, and demobilization costs are largely unchanged for smaller projects.

Steam injection is the lowest cost at $92 per cubic yard. Next is ERH at $120 per cubic yard, then VER/redox at $122 per cubic yard and finally DUS at $138 per cubic yard.

6.4 Recommended Alternative

Regardless of the technology selected, "Scenario 1" (the red and yellow zones) is the recommended approach to source removal at Site 89. DNAPL probably exists outside of the "red zone" (Figure 2-6). If DNAPL is left in place after removal actions are completed, the residual will continue to serve as an ongoing source to the dissolved plume. The presence of residual DNAPL would be expected to greatly extend the life of the project, while reducing the possibility that monitored natural attenuation would be acceptable as a long-term remedy. Due to technology limitations, some DNAPL or very high concentrations in groundwater may remain at some locations.

Although it is more expensive than either steam or VER, ERH is the recommended technology. ERH is considered to be the most predictable and reliable for DNAPL abatement in challenging conditions, such as the Site 89 conditions. ERH will be able to treat the contamination, but exact cost is the primary unknown. DUS is considered cost prohibitive at this time. The increased uncertainty associated with steam or VER may be offset by the potential for significant cost savings, relative to ERH. For this reason, pilot testing of steam injection is recommended. With the presence of two areas, it would be possible to employ ERH on one area and pilot test steam stripping in the other area. Results of the work can be compared and a decision can be made on treating the remaining plume. Table 6-1 presents a relative ranking of the technologies.

Table 6-1
Relative Ranking of Remedial Alternatives

Option	Effectiveness	Implementability	Cost	Total
Steam Injection	3	2	1	6
ERH	1	1	2	4
DUS	2	3	4	9
VER/Frac/Redox	4	4	3	11

Note: This table represents a comparison ranking of the technologies and the factors have equal weighting. The lowest score is the recommended technology.

References

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Time Critical Removal Action Closeout Report, Operable Unit No. 16 (Site 89). OHM Remediation Services Corp. July 2001.

Summary of March/April 2000 Field Work. Baker Environmental, Inc. May 2000.

Summary of October and December 1999 Site Investigation Activities. Baker Environmental, Inc. February 2000.

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Dense Non-Aqueous Phase Liquids (DNAPLs): Review of Emerging Characterization and Remediation Technologies, ITRC Technology Overview, June, 2000.

Thermal Cleanups Using Dynamic Underground Stripping and Hydrous Pyrolysis Oxidation, Newmark, Robin L. et al (Lawrence Livermore National Laboratory), May, 1999.

In Situ Chemical Treatment Technology Evaluation Report, Yujun, Yin and Allen, Herbert (Groundwater Remediation Technologies Analysis Center) July, 1999.

Appendix A

Detailed Cost Estimate

Alternative:	Steam Injection (Scenario 1)	PRELIMINARY COST ESTIMATE SUMMARY
Site:	Site 89	
Location:	Camp Lejeune	
Phase:	FS Evaluation of Options	
Base Year:	2001	
Date:	25-Oct-01	

Description: 36 steam injection wells, 36 combined water/vacuum recovery wells, 32 temperature monitor wells. Steam injection 7 days per week, 24 hours per day. Vapors removed using liquid ring vacuum pump. Water treated by air stripping, combined vapors passed through thermal oxidixer and acid scrubber before discharge to the atmosphere. Treated water passed through liquid phase GAC then discharged to POTW. Steaming duration 7 months

Prepared By:	MJS	Checked By:	TS
Date:	22-Oct-01	Date:	22-Oct-01

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
WELLFIELD INSTALLATION					
Injection Well Installation	395	ft	$100	$39,539	
Injectiion Wellhead Equipment	36	ea	$770	$27,716	
Recovery Well Installation	395	ft	$115	$45,470	
Recovery Pump and Wellhead Equipment	36	ea	$5,536	$199,303	
Thermal Monitoring Wells	32	ea	$1,482	$47,436	
Steam Injection Piping	2,000	ft	$21.00	$42,000	
Water Recovery Piping	2,000	ft	$21.00	$42,000	
Vapor Recovery Piping	1,100	ft	$21.00	$23,100	
Miscellaneous Piping	2,300	ft	$8.00	$18,400	
Insulation	5,100	ft	$4.00	$20,400	
Fittings	1	LS	$5.24	$26,741	
SUBTOTAL				$532,105	
PLANT EQUIPMENT (RENTIAL COSTS)					
Fin Fan Cooler	7	Month	$3,000	$21,000	
Gravity Separator	7	Month	$1,000	$7,000	
Vapor/Water Separator	7	Month	$1,000	$7,000	
Vacuum System	7	Month	$1,500	$10,500	
Air Stripper	7	Month	$2,000	$14,000	
GAC	7	Month	$2,000	$14,000	
Thermal Oxidizer	7	Month	$5,000	$35,000	
Scrubber	7	Month	$1,000	$7,000	
PLC	1	ea	$30,000	$30,000	
Piping and Installation	1	LS	$80,000	$80,000	(Includes electrical)
SUBTOTAL				$225,500	
CONSTRUCTION					
Mobilization/Demobilization/IDW	1	LS	$30,000	$30,000	
SUBTOTAL				$30,000	
PROFESSIONAL SERVICES					
Project Management	1	LS	$19,500	$19,500	Engineer's Estimate
Work Plans, Permits, Reporting, Construction Oversight	1	LS	$71,700	$71,700	Engineer's Estimate
Remedial Design	1	LS	$114,000	$114,000	Engineer's Estimate
SUBTOTAL				$205,200	
TOTAL CAPITAL COST				$992,805	
Profit and G&A	11%			$109,209	
Royalty	5%			$49,640	
Contingency	10%			$115,165	
TOTAL CAPITAL COST				$1,267,000	

OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage	0.00	kW-hr	$0.00	$0	Asssume steam provided at no charge
Natural Gas Usage (assume 500,000 BTU/hr or 5 therm/hr)	43800	therm	$0.69	$30,222	Engineers estimate
Liquid Phase Carbon Usage	8000	lb	$1.60	$12,800	Engineers estimate
SUBTOTAL				$43,022	
SUBCONTRACTOR SERVICES (CONSTRUCTION)					
Periodic Equipment Maintenace	1	LS	$6,000.00	$6,000	EPS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$6,000	
PROFESSIONAL SERVICES					
Project Management	272	hr	$ 105	$ 28,560	8 hrs/week
Operations - Engineering Support	1360	hr	$ 85	$ 115,600	4 hrs/week
Operations - Tech Labor	1360	hr	$ 65	$ 88,400	6 hrs/week
Operations - Tech Labor	1360	hr	$ 65	$ 88,400	6 hrs/week
Operations Supplies	4	ls	$ 250	$ 1,000	Quarterly: Engr est.
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 361,320	
SUBTOTAL				$410,342	
Profit and G&A	11%			$45,138	
Royalty	5%			$20,517	
Contingency	10%			$47,600	
TOTAL ANNUAL OPERATIONS COST				$524,000	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Operations Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	1,267,000	524,000	1,791,000	1	$1,791,000
TOTAL COSTS	1,267,000	524,000	1,791,000	-	$1,791,000

Alternative:	**Electrical Resistance Heating (Scenario 1)**

PRELIMINARY COST ESTIMATE SUMMARY

Site:	Site 89
Location:	Camp Lejeune
Phase:	FS Evaluation of Options
Base Year:	2001
Date:	22-Oct-01

Description: Three phase heating using approximately 200 electrodes, installed to from a depth of 8-12 feet below grade, with an estimated distance of 18 feet between electrodes. One SVE well will be installed at each electrode location, with a total vapor flow rate of 400 cfm. Vapor will be tretaed using two 2,000# granular activated carbon vessels. It is assumed that no groundwwater/steam condensate treatment will be required. Heat will be applied to the saturated zone in two sections, the total time period to heat-up and boil each section is estimated to be 90 days, or 180 days for the entire project. Costs based on budgetary price quote provided by Thermal Remedaition Services (TRS).

Prepared By:	MJS	**Checked By:**	TS
Date:	22-Oct-01	**Date:**	22-Oct-01

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
SUBCONTRACTOR SERVICES (ERH SYSTEM INSTALALTION AND OPERATION)					
Mobilization, Design, Work Plan	1	LS	$58,800	$58,800	TRS
ERH System Installation and Start-Up	1	LS	$616,700	$616,700	TRS
IDW, Demobilization, and Final Report	1	LS	$156,500	$156,500	TRS
SUBTOTAL				$832,000	
PROFESSIONAL SERVICES					
Project Management	1	LS	$25,000	$25,000	Engineer's Estimate
Work Plans, Permits, Reporting	1	LS	$30,000	$30,000	Engineer's Estimate
Construction Oversight	1	LS	$15,000	$15,000	Engineer's Estimate
Start-Up	1	LS	$8,000	$8,000	Engineer's Estimate
SUBTOTAL				$78,000	
SUBTOTAL				**$910,000**	
Profit and G&A	11%			$100,100	
Contingency	10%			$101,010	
TOTAL CAPITAL COST				**$1,111,000**	

OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage (estimated average usage of 1300 kW for 177 days)	5522400	kW-hr	$0.07	$386,568	Engineers estimate
Vapor Phase Carbon Usage	19000	lb	$1.60	$30,400	Engineers estimate
SUBTOTAL				$416,968	
SUBCONTRACTOR SERVICES					
Equipment Operation	1	LS	$522,000.00	$522,000	TRS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$522,000	
PROFESSIONAL SERVICES					
Project Management	52	hr	$ 105	$ 5,460	2 hrs/week
Operations - Engineering Support	104	hr	$ 85	$ 8,840	4 hrs/week
Operations - Tech Labor	156	hr	$ 65	$ 10,140	6 hrs/week
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 63,800	
SUBTOTAL				**$1,002,768**	
Profit and G&A	11%			$110,304	
Contingency	10%			$111,307	
TOTAL ANNUAL OPERATIONS COST				**$1,224,000**	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Operations Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	1,111,000	1,224,000	2,335,000	1	$2,335,000
TOTAL COSTS	1,111,000	1,224,000	2,335,000	-	$2,335,000

Alternative:	Electrical Resistance Heating (Scenario 2)	PRELIMINARY COST ESTIMATE SUMMARY

Site:	Site 89
Location:	Camp Lejeune
Phase:	FS Evaluation of Options
Base Year:	2001
Date:	22-Oct-01

Description: Three phase heating using approximately 26 electrodes, installed to from a depth of 8-12 feet below grade, with an estimated distance of 18 feet between electrodes. One SVE well will be installed at each electrode location, with a total vapor flow rate of 160 cfm. Vapor will be tretaed using two 2,000# granular activated carbon vessels. It is assumed that no groundwwater/steam condensate treatment will be required. The total time period to heat-up and boil the saturated zone is estimated to be 40 days. Costs based on budgetary price quote provided by Thermal Remedaition Services (TRS).

Prepared By:	MJS	**Checked By:**	TS
Date:	22-Oct-01	**Date:**	22-Oct-01

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
SUBCONTRACTOR SERVICES (ERH SYSTEM INSTALALTION AND OPERATION)					
Mobilization, Design, Work Plan	1	LS	$27,500	$27,500	TRS
ERH System Installation and Start-Up	1	LS	$151,500	$151,500	TRS
IDW, Demobilization, and Final Report	1	LS	$31,600	$31,600	TRS
SUBTOTAL				$210,600	
PROFESSIONAL SERVICES					
Project Management	1	LS	$13,000	$13,000	Engineer's Estimate
Work Plans, Permits, Reporting	1	LS	$25,000	$25,000	Engineer's Estimate
Construction Oversight	1	LS	$9,000	$9,000	Engineer's Estimate
Start-Up	1	LS	$5,000	$5,000	Engineer's Estimate
SUBTOTAL				$52,000	
SUBTOTAL				$262,600	
Profit and G&A	11%			$28,886	
Contingency	10%			$29,149	
TOTAL CAPITAL COST				$321,000	

OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage (estimated average usage of 380 kW for 40 days)	364800	kW-hr	$0.07	$25,536	Engineers estimate
Vapor Phase Carbon Usage	8000	lb	$3.00	$24,000	Engineers estimate
SUBTOTAL				$49,536	
SUBCONTRACTOR SERVICES					
Equipment Operation	1	LS	$522,000.00	$50,400	TRS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$50,400	
PROFESSIONAL SERVICES					
Project Management	30	hr	$ 105	$ 3,150	2 hrs/week
Operations - Engineering Support	40	hr	$ 85	$ 3,400	4 hrs/week
Operations - Tech Labor	80	hr	$ 65	$ 5,200	6 hrs/week
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 51,110	
SUBTOTAL				$151,046	
Profit and G&A	11%			$16,615	
Contingency	10%			$16,766	
TOTAL ANNUAL OPERATIONS COST				$184,000	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Operations Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	321,000	184,000	505,000	1	$505,000
TOTAL COSTS	321,000	184,000	505,000	-	$505,000

Alternative:	**Dynamic Underground Stripping (Scenario 1)**		**PRELIMINARY COST ESTIMATE SUMMARY**			

Description: Three phase heating combined with steam injection, using approximately 150 electrodes and 50 steam injection points. ERH electrodes will be installed to from a depth of 8-12 feet below grade, with an estimated distance of 18 feet between electrodes. One SVE well will be installed at each electrode location, with a total vapor flow rate of 400 cfm. Vapor will be tretaed using two 2,000# granular activated carbon vessels. It is assumed that no groundwwater/steam condensate treatment will be required. Heat will be applied to the saturated zone in two sections, the total time period to heat-up and boil each section is estimated to be 90 days, or 180 days for the entire project. Costs based on budgetary price quote provided by Thermal

Site:	Site 89
Location:	Camp Lejeune
Phase:	FS Evaluation of Options
Base Year:	2001
Date:	22-Oct-01

Prepared By:	MJS	**Checked By:**	TS
Date:	22-Oct-01	**Date:**	22-Oct-01

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
SUBCONTRACTOR SERVICES (ERH SYSTEM INSTALALTION AND OPERATION)					
Mobilization, Design, Work Plan	1	LS	$80,800	$80,800	TRS
ERH System Installation and Start-Up	1	LS	$777,300	$777,300	TRS
IDW, Demobilization, and Final Report	1	LS	$181,100	$181,100	TRS
SUBTOTAL				$1,039,200	
PROFESSIONAL SERVICES					
Project Management	1	LS	$30,000	$30,000	Engineer's Estimate
Work Plans, Permits, Reporting	1	LS	$35,000	$35,000	Engineer's Estimate
Construction Oversight	1	LS	$35,000	$35,000	Engineer's Estimate
Start-Up	1	LS	$15,000	$15,000	Engineer's Estimate
SUBTOTAL				$115,000	
SUBTOTAL				**$1,154,200**	
Profit and G&A	11%			$126,962	
Contingency	10%			$128,116	
TOTAL CAPITAL COST				**$1,409,000**	

OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage (estimated average usage of 1300 kW for 177 d	5522400	kW-hr	$0.07	$386,568	Engineers estimate
Vapor Phase Carbon Usage	19000	lb	$1.60	$30,400	Engineers estimate
SUBTOTAL				$416,968	
SUBCONTRACTOR SERVICES					
Equipment Operation	1	LS	$574,986.00	$574,986	TRS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$574,986	
PROFESSIONAL SERVICES					
Project Management	52	hr	$ 105	$ 5,460	2 hrs/week
Operations - Engineering Support	104	hr	$ 85	$ 8,840	4 hrs/week
Operations - Tech Labor	156	hr	$ 65	$ 10,140	6 hrs/week
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 63,800	
SUBTOTAL				**$1,055,754**	
Profit and G&A	11%			$116,133	
Contingency	10%			$117,189	
TOTAL ANNUAL OPERATIONS COST				**$1,289,000**	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Operations Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	1,409,000	1,289,000	2,698,000	1	$2,698,000
TOTAL COSTS	**1,409,000**	**1,289,000**	**2,698,000**	-	**$2,698,000**

Alternative: Multiphase Extraction (Scenario 1)

PRELIMINARY COST ESTIMATE SUMMARY

Description: 45 extraction wells, 20 feet in depth, 20' "ROI", total fluids extraction using liquid ring pump and suction tube recovery from each well with solenoid controlled manifold system (including motorized valves) to cycle liquid extraction between four grounps of ten wells and one group of five. Purged groundwater treated with tray type air stripper and two 600# liquid GAC vessels. Vapors treated with thermal/catalytic oxidizer.

Site:	Site 89
Location:	Camp Lejeune
Phase:	FS Evaluation of Options
Base Year:	2001
Date:	22-Oct-01

Prepared By:	MJS	**Checked By:**	TS
Date:	22-Oct-01	**Date:**	22-Oct-01

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
REMEDIATION EQUIPMENT					
Piping (SDR 11, 2" HDPE)	6000	LF	$0.79	$4,740	Quote from Michigan Pipe Supply
Misc Fittings (SDR 11 HDPE)	1	LS	$1,500.00	$1,500	Quote from Michigan Pipe Supply
Liquid Ring Pump Skid	1	EA	$27,000	$27,000	Quote from DRC
Thermal/Catalytic Oxidizer	1	EA	$65,000	$65,000	Quote from EPG
Tray Air Stripper	1	EA	$24,000	$24,000	Quote from EPG
Liquid Phase GAC Vessels	2	EA	$6,500	$13,000	Quote from EPG
Treatment Building (incl manifolding & appurtances)	1	EA	$75,000	$75,000	Engineers estimate
SUBTOTAL				$210,240	
SUBCONTRACTOR SERVICES (CONSTRUCTION)					
Mobilization/Demobilization	1	LS	$30,000	$30,000	Engineer's Estimate
Impermeable Surface Cover (low density polyethylene liner)	56500	SF	$0.84	$47,460	Engineer's Estimate
Well Installation (4" PVC to 20') and IDW	45	EA	$3,600	$162,000	Richard Simmons Drilling
Trenching (3') and Backfill with Native Soil	1500	LF	$25	$37,500	EPS
Piping Installition	6000	LF	$6	$36,000	EPS
Wellhead Completion	45	EA	$650	$29,250	Richard Simmons Drilling
Electrical (Power Drop and Installation)	1	LS	$10,000	$10,000	Engineers Estimate
Building Support Pad Construction	1	LS	$15,000	$15,000	Engineers Estimate
Piping Connections to Building & Pressure Test	45	LS	$450	$20,250	EPS
Discharge Stack	1	LS	$8,000	$4,500	EPS
SUBTOTAL				$391,960	
SUBCONTRACTOR SERVICES (OTHER)					
Pneumatic Fracturing	1	LS	$85,000	$85,000	ARS Technologies
KMNO4 Injection	1	LS	$750,000	$750,000	ARS Technologies
SUBTOTAL				$835,000	
PROFESSIONAL SERVICES					
Project Management	1	LS	$25,000	$25,000	Engineer's Estimate
Work Plans, Permits, Reporting	1	LS	$30,000	$30,000	Engineer's Estimate
Remedial Design	1	LS	$70,000	$70,000	Engineer's Estimate
Construction Oversight	1	LS	$23,000	$23,000	Engineer's Estimate
Start-Up	1	LS	$11,000	$11,000	Engineer's Estimate
Other Construction Oversight	1	LS	$18,000	$18,000	Engineer's Estimate
SUBTOTAL				$177,000	
SUBTOTAL				**$1,614,200**	
Profit and G&A	11%			$177,562	
Contingency	10%			$179,176	
TOTAL CAPITAL COST				**$1,971,000**	

ANNUAL OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage (total estimated 65 hp electric motors, 48.47 kW)	424600	kW-hr	$0.07	$29,722	Engineers estimate
Natural Gas Usage (assume 500,000 BTU/hr or 5 therm/hr)	43800	therm	$0.69	$30,222	Engineers estimate
Liquid Phase Carbon Usage	9600	lb	$1.60	$15,360	Engineers estimate
SUBTOTAL				$75,304	
SUBCONTRACTOR SERVICES (CONSTRUCTION)					
Periodic Equipment Maintenace	1	LS	$6,000.00	$6,000	EPS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$6,000	
PROFESSIONAL SERVICES					
Project Management	104	hr	$ 105	$ 10,920	2 hrs/week
Operations - Engineering Support	208	hr	$ 85	$ 17,680	4 hrs/week
Operations - Tech Labor	312	hr	$ 65	$ 20,280	6 hrs/week
Operations Supplies	4	ls	$ 250	$ 1,000	Quarterly: Engr est.
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 89,240	
SUBTOTAL				**$170,544**	
Profit and G&A	11%			$18,760	
Contingency	10%			$18,930	
TOTAL ANNUAL OPERATIONS COST				**$208,000**	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Annual O&M Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	1,971,000	0	1,971,000	1	$1,971,000
1	0	208,000	208,000	0.969	$201,552
2	0	208,000	208,000	0.939	$195,312
TOTAL COSTS	1,971,000	416,000	2,387,000	-	$2,367,864

Alternative:	**Multiphase Extraction (Scenario 2)**	**PRELIMINARY COST ESTIMATE SUMMARY**		
Site:	Site 89			
Location:	Camp Lejeune			
Phase:	FS Evaluation of Options			
Base Year:	2001			
Date:	22-Oct-01			
		Prepared By: MJS	**Checked By:** TS	
		Date: 22-Oct-01	**Date:** 22-Oct-01	

Description: 7 extraction wells, 20 feet in depth, 20' "ROI", total fluids extraction using liquid ring pump and suction tube recovery from each well with solenoid controlled manifold system (including motorized valves) to cycle liquid extraction between four grounps of ten wells and one group of five. Purged groundwater treated with tray type air stripper and two 600# liquid GAC vessels. Vapors treated with thermal/catalytic oxidizer.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
REMEDIATION EQUIPMENT					
Piping (SDR 11, 2" HDPE)	1000	LF	$0.79	$790	Quote from Michigan Pipe Supply
Misc Fittings (SDR 11 HDPE)	1	LS	$500.00	$500	Quote from Michigan Pipe Supply
Liquid Ring Pump Skid	1	EA	$25,000	$25,000	Quote from DRC
Thermal/Catalytic Oxidizer	1	EA	$45,000	$45,000	Quote from EPG
Tray Air Stripper	1	EA	$18,000	$18,000	Quote from EPG
Liquid Phase GAC Vessels	2	EA	$4,000	$8,000	Quote from EPG
Thermal/Catalytic Oxidizer	1	EA	$65,000	$65,000	Quote from EPG
Treatment Building (incl manifolding & appurtances)	1	EA	$65,000	$65,000	Engineers estimate
SUBTOTAL				$227,290	
SUBCONTRACTOR SERVICES (CONSTRUCTION)					
Mobilization/Demobilization	1	LS	$30,000	$30,000	Engineer's Estimate
Impermeable Surface Cover (low density polyethylene liner)	8750	SF	$0.84	$7,350	Engineer's Estimate
Well Installation (4" PVC to 20') and IDW	7	EA	$3,600	$25,200	Richard Simmons Drilling
Trenching (3') and Backfill with Native Soil	250	LF	$25	$6,250	EPS
Piping Installtion	1000	LF	$6	$6,000	EPS
Wellhead Completion	7	EA	$650	$4,550	Richard Simmons Drilling
Electrical (Power Drop and Installation)	1	LS	$8,000	$8,000	Engineers Estimate
Building Support Pad Construction	1	LS	$10,000	$10,000	Engineers Estimate
Piping Connections to Building & Pressure Test	7	LS	$450	$3,150	EPS
Discharge Stack	1	LS	$6,000	$4,500	EPS
SUBTOTAL				$105,000	
SUBCONTRACTOR SERVICES (OTHER)					
Pneumatic Fracturing	1	LS	$10,000	$10,000	ARS Technologies
KMNO4 Injection	1	LS	$75,000	$75,000	ARS Technologies
SUBTOTAL				$85,000	
PROFESSIONAL SERVICES					
Project Management	1	LS	$20,000	$20,000	Engineer's Estimate
Work Plans, Permits, Reporting	1	LS	$30,000	$30,000	Engineer's Estimate
Remedial Design	1	LS	$55,000	$55,000	Engineer's Estimate
Construction Oversight	1	LS	$18,000	$18,000	Engineer's Estimate
Start-Up	1	LS	$11,000	$11,000	Engineer's Estimate
Other Construction Oversight	1	LS	$12,000	$12,000	Engineer's Estimate
SUBTOTAL				$146,000	
SUBTOTAL				**$563,290**	
Profit and G&A	11%			$61,962	
Contingency	10%			$62,525	
TOTAL CAPITAL COST				**$688,000**	

ANNUAL OPERATIONS COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CONSUMEABLES					
Electrical Usage (total estimated 45 hp electric motors, 33.56 kW)	293986	kW-hr	$0.07	$20,579	Engineers estimate
Natural Gas Usage (assume 300,000 BTU/hr or 3 therm/hr)	26280	therm	$0.69	$18,133	Engineers estimate
Liquid Phase Carbon Usage	5000	lb	$1.60	$8,000	Engineers estimate
SUBTOTAL				$46,712	
SUBCONTRACTOR SERVICES (CONSTRUCTION)					
Periodic Equipment Maintenace	1	LS	$5,000.00	$5,000	EPS
GW Sample Analysis	52	sample	$ 200	$ 10,400	(4) Quarterly Sampling Events - 7 wells, (7) BTEX analysis (SW 8021), (6) PAH analysis (SW-8310), plus (6) QA/QC samples
Air Sample Analysis	24	sample	$ 150	$ 3,600	Monthly, off gas influent/effluent
SUBTOTAL				$5,000	
PROFESSIONAL SERVICES					
Project Management	104	hr	$ 105	$ 10,920	2 hrs/week
Operations - Engineering Support	208	hr	$ 85	$ 17,680	4 hrs/week
Operations - Tech Labor	312	hr	$ 65	$ 20,280	6 hrs/week
Operations Supplies	4	ls	$ 250	$ 1,000	Quarterly; Engr est.
Sampling Supplies	1	ls	$ 500	$ 500	Engineer's estimate
GW Sampling Equipment Rental	8	day	$ 220	$ 1,760	CH2M std rates
As-Builts/Reporting - Engineer Labor	360	hr	$ 85	$ 30,600	Construction Completion Report, Quarterly reports (3)
As-Builts/Reporting - Tech Labor	100	hr	$ 65	$ 6,500	Construction Completion Report, Quarterly reports (3)
SUBTOTAL				$ 89,240	
SUBTOTAL				**$140,952**	
Profit and G&A	11%			$15,505	
Contingency	10%			$15,646	
TOTAL ANNUAL OPERATIONS COST				**$172,000**	

PRESENT WORTH VALUE ANALYSIS

Year	Capital Cost ($)	Annual O&M Cost ($)	Total Cost ($)	Discount Factor at 3.2% (P/F)	Total Present Value Cost at 3.2% ($)
0	688,000	0	688,000	1	$688,000
1	0	172,000	172,000	0.969	$166,668
2	0	172,000	172,000	0.939	$161,508
TOTAL COSTS	688,000	344,000	1,032,000	-	$1,016,176